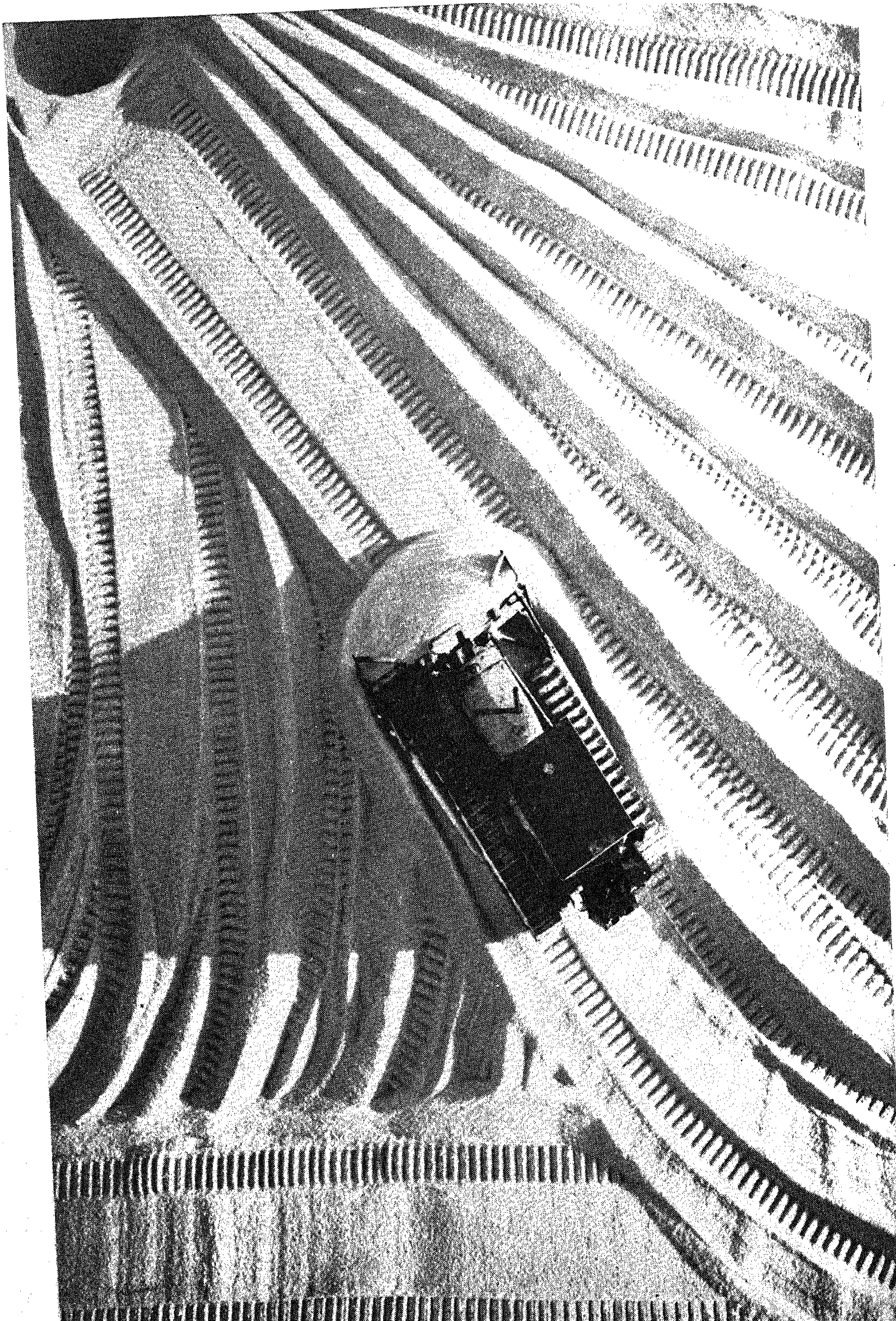

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A mountain of salt, ready for shipment.

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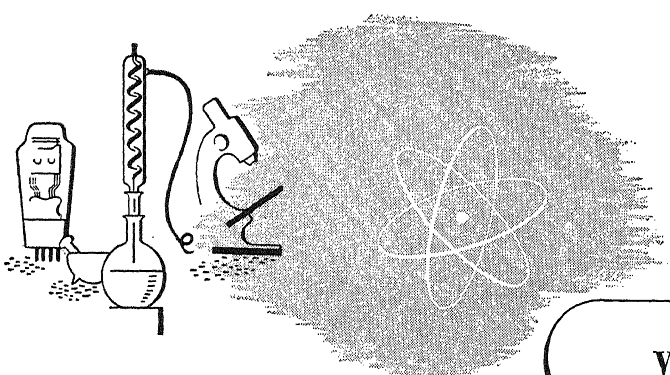

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CONTENTS OF VOLUME V

THE BASIS OF PLANT LIFE

Protoplasm, the Stuff from Which All the Varieties of Plant Life Spring and Are Fed

THE BED-ROCK OF THE STUDY OF ORIGINS

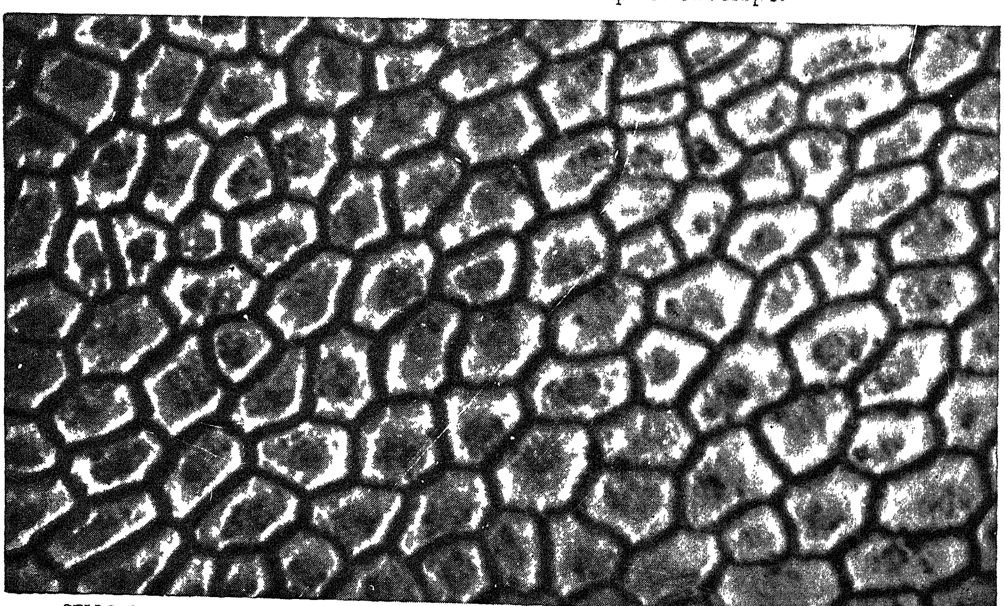
IN several sections of this work dealing with the phenomena of life, animal life and plant life, references have been made to the wonderful substance which may be regarded as the basis of life, namely, protoplasm. Some of its properties and qualities have been discussed, but we have now to examine it rather more systematically. It is the living principle in all plant life, and the study of protoplasm is more easily and successfully carried out in connection with plants than with animals. That is why students who are entering upon any kind of biological training begin that training with the study of plants. What they learn in the study of botany is really the sum total of the infinite variety of possibilities that there are in the activities of protoplasm.

We may take a swift glance at the history of the main discoveries in plant knowledge, all of which, of course, have had attention drawn to them originally by men who were in search of knowledge which would help them to understand what life itself is. All these investigations of a biological kind are ultimately efforts to answer the question "What is life?" Perhaps the greatest stimulus to the search for this knowledge was given to mankind by the discovery of magnifying glasses, and subsequently of the microscope. It was thought that these, by revealing what was taking place in among the minute structures of living things, structures far too minute to come under the observation of the human eye unaided, would throw some light upon the nature of life itself.

One can readily appreciate the state of mind, therefore, of the Dutch naturalist Jan Swammerdam, who actually destroyed the notes he had made of what he had seen through his primitive lenses, and came to regard such work as sacrilege. Another Dutch naturalist, Antony van Leeuwenhoek, made a number of observations from 1632 on, none of which were accepted at the time, so extraordinary did they appear to those who had not used a magnifying glass. It was reserved for Robert Hooke, curator of experiments to the Royal Society, to substantiate the fact that very minute organisms, much smaller than had hitherto been imagined, could be seen under the magnifying glass. In order to carry conviction to others, those who had seen them at the meeting (1667) where they were shown, signed a document to that effect. The creatures were noticed in different kinds of infusions, hence the name "Infusoria". What these early observers actually saw were some unicellular, lowly creatures, and a number of what we now know to be spores of plants.

From this time on study under powers of magnification became the rule, and very soon observers discovered the special structures in leaves, and stems, and wood; and because these structures suggested to them the appearance of honeycomb they gave them the name of "cells". At that early time it was the walls of these cells to which the chief interest attached. It was not yet suspected that the material which filled the honeycomb — the honey — was really the important thing. The structures were observed to grow, but how was not known.

Then at the beginning of the nineteenth century it was noticed that the contents of some of these cells were sometimes extruded into the surrounding water, that these contents looked like little masses or globes of jelly; furthermore, some of these masses were observed ultimately to come to rest and grow into filaments and other structures; and so the distinction gradually came to be recognized that the cell consisted of two parts as a rule, the outer portion, or cell-wall, and an inner, softer material of a slimy or gelatinous nature. This latter apparently lives in the cell, much as a snail lives in its shell. Sometimes it shows no parts, but is homogeneous, but in other cases it was found those little organisms which occupy cells made by themselves. This name is "protoplasts". These protoplasts may live as single individuals, and many do so and, on the other hand, they may be aggregated together in great numbers so as to form the arrangement suggested by the honeycomb In this latter case, however, it is to be noted that between the individual protoplasms there are frequently channels or spaces, and in other cases the protoplasms, or cells, are joined together by a kind of glue or cement, which the botanists term "intercellular substance" When this substance is removed and the cells separated, we see that each cell has its own complete envelope.



CELLS OF THE LEAF OF BOX-SHRUB, SHOWING THEIR WALLS AND PROTOPLASM CONTENTS

that it could be differentiated into quite a number of parts, such as threads, nodules and so forth. Many of these facts were discovered by Professor Hugo von Mohl, of Tübingen, who, in 1846, applied to this gelatinous viscid substance, which filled the cell as the honey filled the honeycomb, the name of "protoplasm". Hence arose these two terms which from that time on have been the center of such an immense amount of work, the cell and cell-protoplasm.

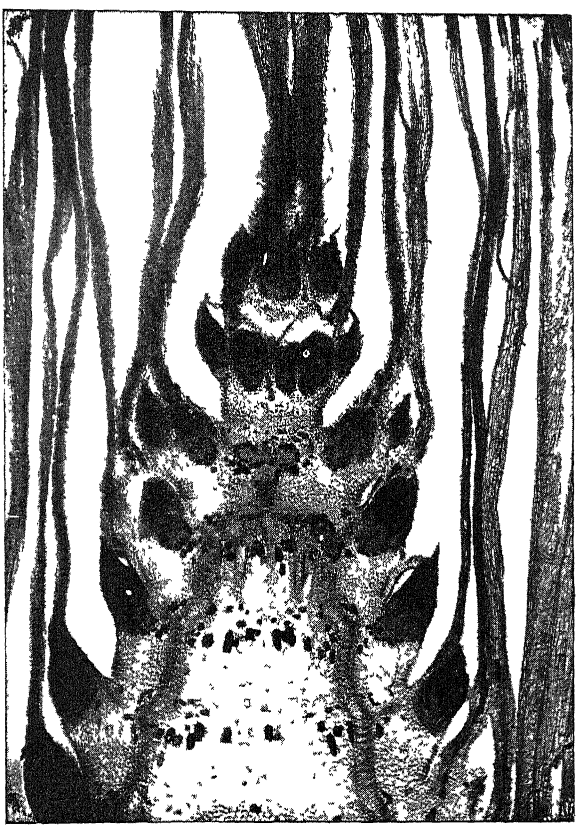
A more recent name, but one to which we must attend, has been given to all

Thus the most accurate conception we can give of cells, and collections of cells, is to regard them as analogous to the shells of some living animals, either solitary individuals or associated together in groups, and attached to each other. When this latter condition obtains, some of the protoplasts are set apart for one function and some for another. The development of new cells goes on inside those already formed by their own activity, so that the protoplasts are not only the building, but they are the building materials and the builders all in one.

This is an essential conception of protoplasm which we must make clear in our minds, because it is this very fact which alone distinguishes organic from inorganic substances Thus the work of these living cells includes the duty of collecting and absorbing nourishment, so making possible the phenomenon of growth, the maturing of further generations of cells, the choosing of their environment, and their protection from injury. In other words, all the duties of life for a living organism are ultimately thrown back upon the cell and its contained protoplasm.

Among the various properties which this wonderful substance has is that of motion — it is a motile substance. It can be observed to change its shape at will, and sometimes single protoplasts are furnished with hair-like organs, or cilia, which are also means of movement. They are not, however, necessary for this purpose. Protoplasts can change their outlines by simply projecting parts of themselves in one direction and withdrawing other parts. This gives a sort of creeping movement and is particularly noticeable in what is termed "naked protoplasm" — that is, in protoplasm which is not confined within a cell-wall.

Protoplasm, however, also moves when it is within a cell, but in this case, of course, its movements are limited by its walls. As the cell-wall grows the protoplasm within clings to it, and should it not increase with equal rapidity, spaces or vacuoles are left within it. Currents, actual streams of protoplasm, are observed also within cells; in short, quite a number of movements under the microscope.



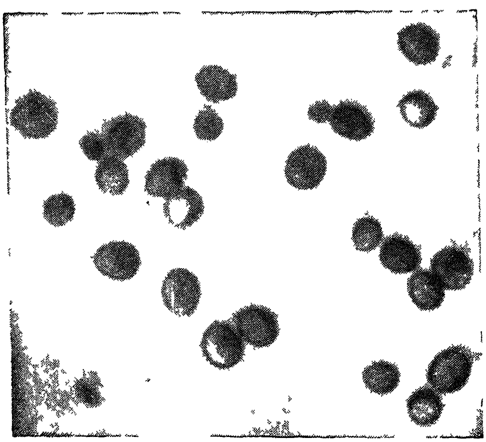
THE GROWING POINT OF HORSE-TAIL

The result of the growth of the cell-wall is that the protoplasm which sticks to that wall stretches across the empty spaces within in the form of threads or strands.

Along these strands there may be seen at times a definite movement backwards and forwards of small dark granules, which serve to make plain the direction of the current. Other particles in the protoplasm, such as the green coloring matter in plants, appear to be unaffected by these movements and remain still. In other words, the protoplasm appears to pass over these granules. It is from observations such as these that we learn that the protoplasm within the cell is really divided into two parts, an outer somewhat tougher portion, and an inner more mobile part, these being termed respectively the "ectoplasm" and the "endoplasm". It is within the latter, of course, that the moving granules and particles are seen.

Similar movements and others may be observed in connection with the protoplasm of unicellular creatures, which in addition, however, occasionally show a movement of two individuals towards each other and the actual fusing together of these two simple organisms on coming into contact.

It must not, however, be supposed that all cell protoplasm is of exactly the same constitution. In fact, the minute study of its behavior in different plants and different cells has forced observers to form the opinion that there is such a thing as what is called "*the specific constitution of protoplasm*". This phrase requires a word or two of explanation, and the idea that it is intended to convey is one which we must endeavor to grasp. It is found that the protoplasm of different kinds of cells requires for its nourishment and growth different particles or elements which it is able to abstract from its surroundings. It is because of this specific character, evidently, that protoplasm is able to build itself up into the great variety of tissues and organisms in which it manifests itself.



A YEAST PLANT BUDDING NEW CELLS

In other words, protoplasm has a *constitution* rather than a composition. The former term implies more than the latter. True, it is composed of certain chemical elements, but that is not the whole truth. The protoplasm of different plants, although so composed, exhibits the differences we have mentioned — that is to say, it is *constituted* differently in the different species. Hence it is more accurate and more explanatory to speak of the constitution of protoplasm rather than its composition.

The chemical formula can be given for the composition of protoplasm. True, but no chemical formula can be given for the protoplasm of different species of plants. Each protoplast may be said, therefore, to represent an organism which contains many chemical compounds, and these it can renew when necessary, and modify their arrangements in response to the environment. There is, however, undoubtedly some very minute and intimate structure in protoplasm, enabling it to perform its complicated functions, which is at present beyond our knowledge, but which is best expressed by saying that protoplasm has a specific constitution.

So infinitely delicate and minute, however, must be the ultimate structure of living protoplasm that it is not certain we shall ever be able actually to see the mechanism itself which builds up the living part of the cell. The mental picture which we form, therefore, of the smallest masses of protoplasm must be largely theoretical. Not so, however, their results, because we can actually see what this protoplasm does — that is to say, there is such a thing as its visible constructive activity.

This watching of protoplasm at work is best seen in the large single-celled bodies of the lowly group of organisms called the "myxomycetes". One of these lowly organisms is that which may be seen in the shape of a sticky yellow mass on the dry bark of the branches of fallen pine trees, where its appearance suggests that of yolk of egg. This covers a large portion of a branch in a thin layer. If this mass be watched during the hours of darkness, a most remarkable change is seen to take place in it. Instead of being now a smooth, slimy covering, it is observed to change its form in certain places into a number of warty projections, giving the whole thing a coarse granulated look. Towards morning, from these lumps small pear-shaped bodies on stalks make their appearance, and the lumps themselves are no longer sticky or viscous, but have become a mass of fine hairs, or threads, with numerous minute black spores lying between them. This whole process takes about twelve hours to accomplish.

Other organisms of this same group go through a similar series of changes, resulting, however, in quite different shapes, so

that we here have what we call an example of the visible constructive activity manifested in protoplasm, an activity the results of which are quite obvious to the unaided eye which may be watching them, ultimately caused by a mechanism so delicate as to be invisible to the strongest microscope.

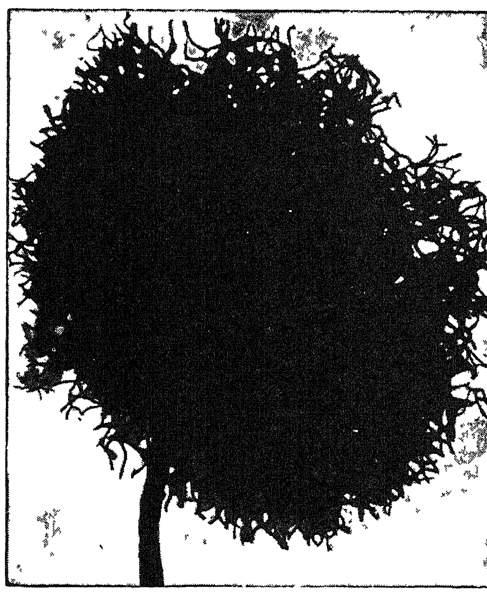
Where there is a cell-wall surrounding the protoplasm, it frequently behaves very like the skin of an animal rather than as a rigid covering. That is to say, it does not hinder the movements of the protoplasm within, or its changes in shape, but it adapts itself to them, even though it may take no part in the actual process of growth. Sometimes it perishes as these are completed; in other cases it remains changed in aspect with the protoplasm itself. It is on account of these constructive activities of protoplasm that we find in other plants than those just mentioned the processes in protoplasm known as "segregation", "gemmation" and "cell division".

In segregation, the protoplasm divides inside a rigid cell-wall into a number of separate portions all exactly the same shape. No partitions are formed in the cell, but new cell-walls are formed by each separate mass of protoplasm within for itself. In this way sometimes more than a thousand small bodies may arise inside one cell, each ultimately having its own wall. Naturally, the larger these are the fewer the number, and vice versa. Moreover, they vary immensely in shape. They may be round, oval, pear-shaped, thread-like, straight, spiral, or twisted, and so forth — another example of the visible constructive activity of protoplasm.

Gemmation differs from segregation in that here a portion of protoplasm is protruded from the general mass like a bud, which gradually increases in size until it is as large as that from which it originally protruded. Eventually, the bud and the original mass separate. This is typically seen in the yeast plant.

In true cell-division the protoplasm within the cell develops a partition which ultimately divides the protoplasm into halves, so that two chambers are produced. By repetition of this process is obtained a multicellular organism, like any of the higher plants or animals. The details of cell-division have been described in an earlier chapter in the section on Life. We have, therefore, said sufficient here to give some idea of the nature and composition of protoplasm and its properties as manifested in the lowliest plants. We shall have more to say on a further aspect, however, when speaking of reproduction in connection with seeds and fruits.

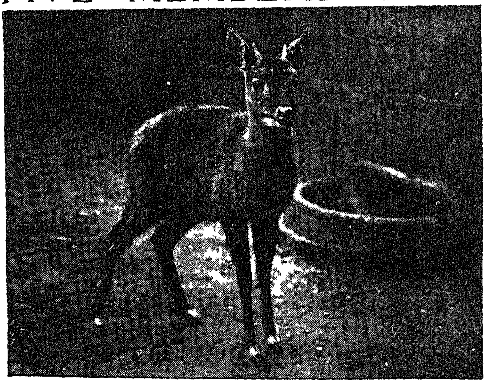
The earliest systematic attempt to produce an account of plant life is that of Pliny the Elder (born A.D. 23), in his "*Historia Naturalis*", which deals with a wonderful variety of subjects, including the elements, the stars, the winds, the geography of the world, the organization of man, notable characters, inventions, a system of zoölogy treating of birds, fishes, insects and man, and then devotes sixteen books to botany.

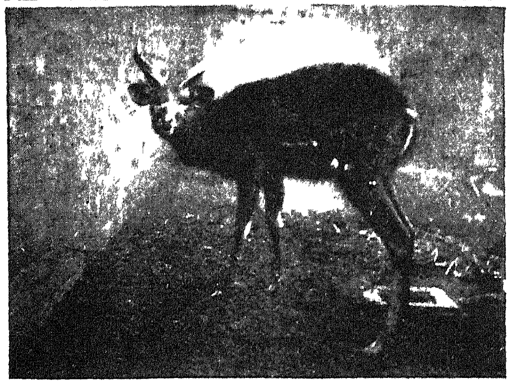


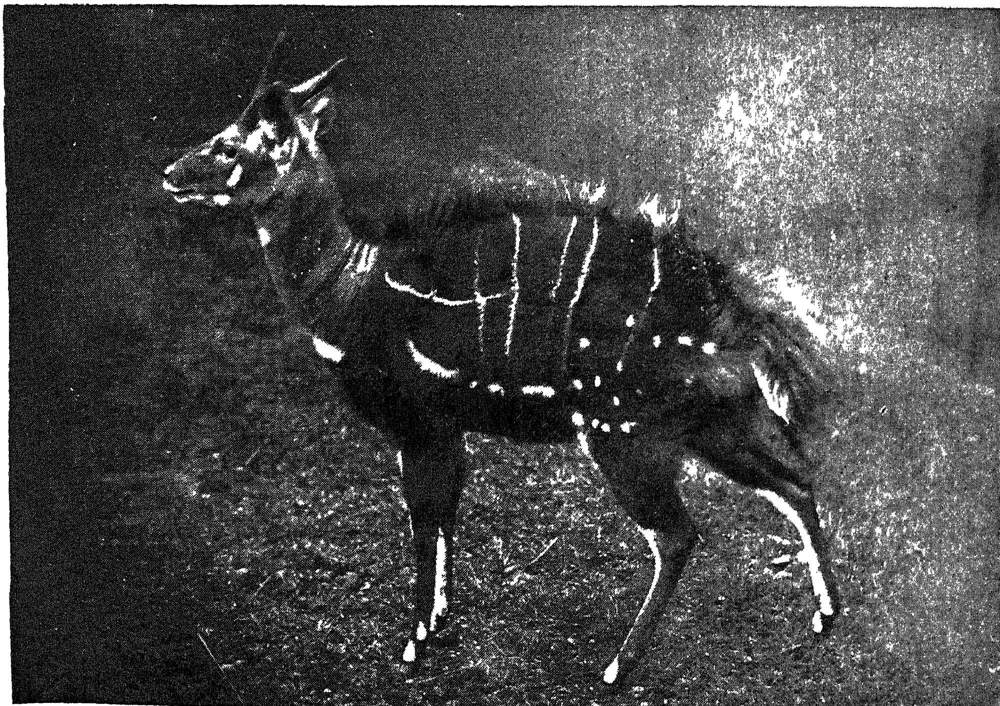
MYXOMYCETES WITH SPORE-BEARING HEAD

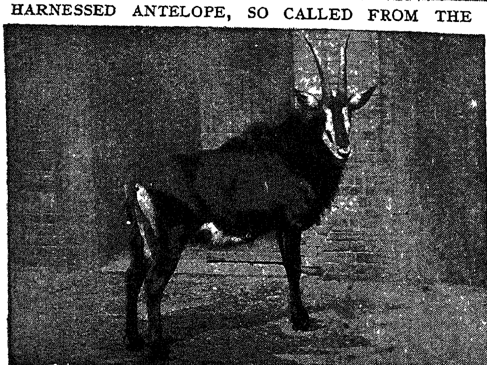
In them Pliny gives an account of the various trees, herbs, fruits, etc., and the medicines and drugs which were obtained from them, chiefly facts or suppositions which he had found recorded by various authors. From these he selected just what he liked without much system or judgment, so that from the strictly scientific point of view the work is of no great value.

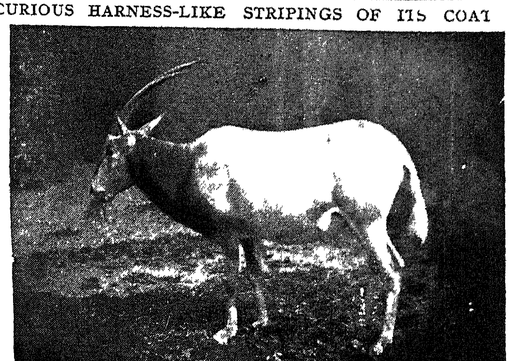
FIVE MEMBERS OF THE ANTELOPE GROUP


THE ANOMALOUS FOUR-HORNED ANTELOPE


A DENIZEN OF THE SWAMP THE MARSHBUCK


HARNESSED ANTELOPE, SO CALLED FROM THE CURIOUS HARNESS-LIKE STRIPINGS OF ITS COAT


THE SABLE ANTELOPE


A SABER-HORNED ORYX

The photographs on these pages are by Messrs. W. P. Dando and Lewis Medland

THE ANTELOPE FAMILY

A Group of Animals Inhabiting all Uncultivated Lands from Jagged Mountain Tops to Sandy Plains

THE LINK BETWEEN GOATS AND CATTLE

AT some botanical gardens a scheme is carried out whereby the visitor is able to see, growing side by side, gathered from many lands, all or nearly all the available species of the particular plant or tree in which he is interested. Now, if we could get together a really representative assemblage of all the animals which come within the limits of our present chapter, we could set the best of naturalists a stiff problem by asking where, on the one hand, the goats end and antelopes begin; and where, on the other hand, the antelopes end and the special cattle begin. The problem is a most difficult one. Step by step we are led on from the sheep and goats by the tahrs, the gorals, the serows and the takins, and, sandwiched between these and the first possible genus of antelopes, the Rocky Mountain goat, we have the musk-ox; then, after the musk-ox and the so-called "goat", the chamois.

Antelopes are hollow-horned ruminants — that is to say, animals which chew the cud. Unlike the antlers of the deer, which, as we have seen, are shed every year, the horns of the antelopes are permanent growths. But oxen and sheep and goats are hollow-horned ruminants, too. Antelopes are none of these, obviously, so the rule observed in establishing the classification is, if an animal be a ruminant and possess hollow horns with a bony core, to relegate it to the antelope group.

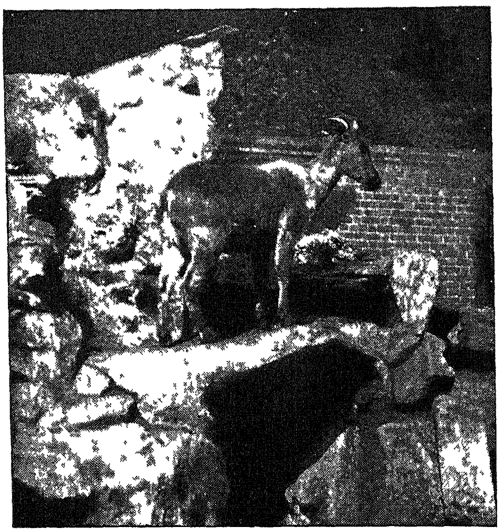
It is not satisfactory, for we get the most diversified aggregation of animals imaginable. We have in one and the same group pygmy creatures no bigger than rabbits, and weighing about as little, and at the other end we have lordly beasts such as the eland, standing over six feet at the withers, and weighing up to 1500 pounds and more. Even with so elastic a grouping as this, there are left out the animals already cited. They take precedence of the antelopes, and, in the order given, each constitutes a separate genus of the bovine family. They are more or less closely allied both to goats and sheep and antelopes, yet we have, in the larger group, antelopes which are quite isolated from all other existing antelopes, the story of whose descent must be sought in the records of geology. Even with the denizens of the debatable land omitted — the tahrs, serows, etc. — there remains a formidable array of animals for our group, numbering, with the Rocky Mountain goat and the chamois, 7 sub-families and some 150 species.

And what of these outlanders? The tahr, which is also called the Himalayan goat, and, as to one species, the Nilgiri ibex, differs so pronouncedly from the true goats that it is referred to a genus of its own, where it forms a genealogical stepping-stone between the goats and the antelopes. It is a forest-haunting animal found on the mountain sides. A stout, stocky beast, the male attains a height of from thirty-six to forty inches at the shoulder. The goral is a goat-like animal still nearer the antelopes, three to four inches less in height than the tahr, and having as its nearest ally the serow, a shaggy ruminant of southern and southeastern Asia, larger than the tahr, haunting the forest-clad upper slopes of the mountains, a slow-moving beast on the flat, but splendidly agile among rocks, and courageous to a fault when danger threatens from any foe, animal or human.

The takin comes next in order of relationship, a powerfully built animal, with horns resembling those of the musk-ox. It is a native of the almost inaccessible mountains of eastern Tibet and Bhutan.

Both serows and takins are regarded now as related to the Rocky Mountain goat. This interesting animal dwells in the high ranges of the coastal mountains in British Columbia and Alaska, rarely coming much below timber line in summer and only so far down in winter as the snow compels it to descend. It is short and heavy-limbed, and not particularly alert, depending for the avoidance of man upon its powers of concealment in the shadow of boulders and rocks rather than upon speed. Its coat consists of long, shaggy white hair, which is beautifully soft and warm, and was made much use of in former times by the Indians. Its food consists mainly of a kind of moss; and it is virtually exempt from harm, since its thick hide and its sharp, disemboweling horns resist the attacks, in most cases, of any lynxes or bears that try to overcome it. This animal developed when America was so sparsely peopled that man did not give it occasion to make a high speed necessary; and it is a fortunate fact that, with cheaper materials on the market for blanket-making, the animal is not now so valuable to the hunter, and thus has the opportunity peacefully — in parts of its range, at all events — to renew its depleted numbers It would be interesting to see what a first-rate sheep-breeder would evolve from the Rocky Mountain goat. It would start fairly, possessing as it does a thick coat of wool beneath its longer outer covering of snow-white hair

Another intermediate animal, peculiar to North America, is the pronghorn — a beautiful antelope-like creature that formerly ranged in enormous migratory bands all over the dry plains and valleys between the Missouri River and the Sierra Nevada. It was fawn-colored above and white beneath, and the bucks bore horns that were lyre-shaped when seen in front, and had on each one a short prong — something not known in any other member of this group. It therefore is classified in a family by itself, containing only this one species — *Antilocapra americana.* Furthermore, from time to time these horns were shed, and replaced by a new pair, which occurs in no other antelope or goat. The pronghorns have been so disturbed by settlements, railroads, etc., in their ancient ranges, and so mercilessly shot for food and for sport that now only a few remain in remote and secluded parts of the Far West.



LINKING GOATS AND ANTELOPES — THE TAHR

THE TAKIN — A HIMALAYAN ANTELOPE

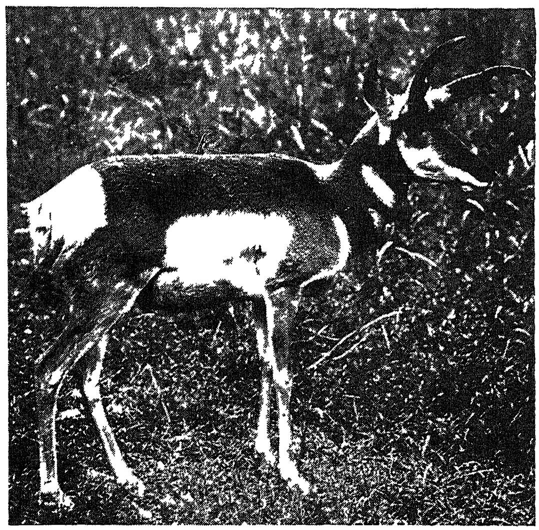
The chamois are the last of the goat-like animals which must be included among the antelopes.

All species of chamois agree generally in habits. The majority of them keep near the woods with which the mountain sides are clothed, and it is only the few, and not the generality, which at certain seasons of the year betake themselves to the higher, more exposed ranges; and these return with speed to the protection of the forests when inclement weather comes. The food of all consists of lichen and scanty herbage, a diet from which they manage to extract nourishment sufficient for strength and beauty and climbing powers excelled by hardly any other animal. A good buck may weigh from 50 to 70 pounds, yet he will scale the dizziest peak

A KING OF THE ALPS — THE CHAMOIS

and stand poised upon a pinnacle with all four feet securely placed, though the space occupied could be almost covered by a silver dollar. So now to the antelopes proper, the parent stock, it is believed, of the more specialized cattle and goats. The eland heads the list, but as this animal has already been mentioned in an earlier chapter we need refer here only to an interesting fact as to its capture noted by Hagenbeck. The adult animals, for all their weight and size, are too speedy and enduring, unless excessively fat, to be captured on horseback, though, of course, they can be shot. It is the young eland that the hunter must run down. These can be cut out of a herd by a well-mounted man.

As soon as captured its hind legs are tethered, the animal is swathed in a warm rug, and a subcutaneous injection is administered. This throws the young eland into a profound slumber that lasts nearly twenty-four hours, and at the end of this time it is ready to accept a milch cow as foster-mother. These precautions are necessary from the fact that after a chase the young animal is thrown by exertion and terror into a profuse sweat, and, unless treated in this manner, a reaction, accompanied by rapid lowering of temperature, follows, with the result that the animal dies in the course of a quarter of an hour from acute exhaustion.



Courtesy National Zoological Park

PRONG-HORN ANTELOPE

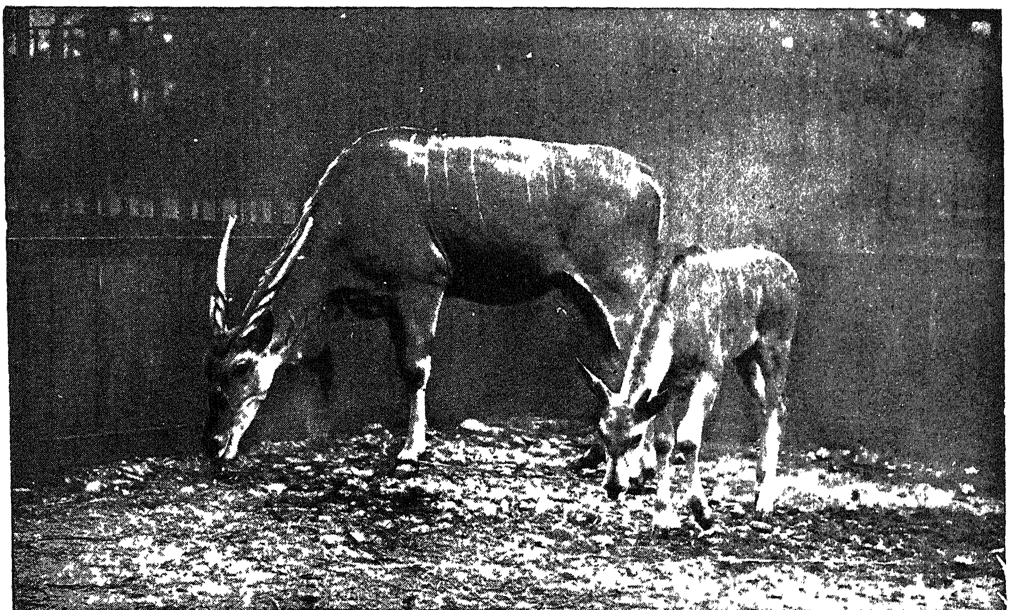
One of the distinguishing features of the antelopes is the fact that horns are borne, as a rule, only by the males, yet of the first three genera, the elands, the bongos and the kudus, the first and third are exceptions to such rule, though, of course, the appendages are smaller in the females than in the other sex. The bongo is a large and powerfully built animal, the adult bull standing about four feet at the shoulder, and carrying horns measuring 35 inches in a straight line. It is a forest-haunting antelope, but the handsome kudu, which is still larger, standing as much as 52 inches at the withers, with horns up to four feet in length, is considerably less restricted in its range. It is equally at home

in the dense thickets of the hill country and the tangled scrub and thorn jungles of lower levels. Blessed with wisdom enough to flee, when pursued, to the highest and roughest part of their range, these antelopes make their pursuit extremely difficult to the mounted hunter, even if he be prepared to brave the terrors of the tsetse fly, whose bite is fatal to the horse.

The term "harnessed antelopes", with which we frequently meet, embraces three distinct species, the nyala, the bushbuck and the sitatunga, or nakong, commonly known as the marshbuck. The genus is confined to Africa, but has its Oriental representative in the Indian nilgai. The nyala haunts the low-lying, fever-ridden swamps of southeastern Africa, and so enjoys relative immunity from the light-hearted persecution of the foreign sportsman, who has done so much in our generation to divest Africa of some of the chief glories of her fauna.

The bushbuck, which is smaller than the nyala, ranges from Abyssinia to the Cape, with many interesting variations according to locality. The marshbuck keeps to marshy areas, and is frequently seen among the reeds with all but its head and horns submerged. It varies so much with its habitat that only by the strictest vigilance have naturalists repressed the tendency to term many of these varieties new species. The differences are mainly as to size and coloration, but one cardinal point of resemblance is in the interesting modification of the hoofs of all marshbuck, which are enormously lengthened to suit a life spent upon a clinging, boggy surface, and the negotiation of masses of drowned or floating vegetation.

The whole study of the hoofs of antelopes is profitable and suggestive The hoofs show surprising variation, or perhaps it would be more correct to say that surprisingly different results are attained from the variations which present themselves. The hoofs of each species, or genus, are beautifully adapted to the special circumstances of the animal's life, whether that life be passed among precipitous rocks, in treacherous bog, or the loose, yielding sand of the desert. We have here surprising examples of the adaptation of quadrupedal equipment to environment, and while the foot of the desert antelope leaves the camel owner marveling, the klipspringer's feats, achieved with such tiny hoofs, reduce the hardiest human mountaineer to despair.



THE SUPREME DEVELOPMENT OF THE ANTELOPE — AN ELAND COW WITH HER CALF

Although, as we have seen, the nilgai is the Oriental representative of the harnessed antelope, it is known in its native land as the "blue bull", or blue ox, such being the English of the name by which it is familiar to us This animal is remarkable among antelopes from the fact that its fore-limbs are longer than the hind pair, so that the height of the withers, expressed in figures, gives an erroneous impression of the animal's size The color of the bull is a dark bluish gray, hence its name, and its height may vary from 51 to as much as 58 inches. Fossil deposits show that the nilgai once had a far more extended range than it now enjoys, for at present it occurs only within a well-defined area in India. Seeing that it carries insignificant horns, that its flesh is unpalatable, and that firearms have nullified the value of the shields formerly made from its hide, this antelope should have a very good chance of continuing in abundance, for its economic value is small. But there is the game hunter, of course, and the nilgai is a dear prize in his vain and wanton campaigns.

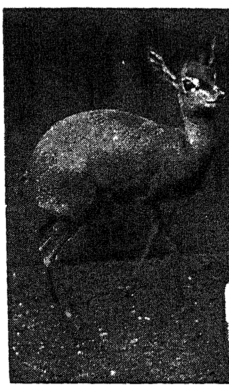
NILGAI ANTELOPES IN THE SNOW AT A ZOÖLOGICAL GARDEN NEAR HAMBURG

We pass next to an interesting antelope, the chousingha, or four-horned antelope, an animal restricted to thin forest land at the foot of the Himalayas. This animal, as its name indicates, has for some remarkable reason, which it is impossible now to fathom, developed a second pair of horns, the larger pair placed far back, the second and smaller being immediately over the eyes. We find horns of a very different type in a group of antelopes in which the addax heads the list. In this group the horns are long and cylindrical — in both sexes — and either straight, spiral or curved. The addax interests us from its isolation from kinship with all existing antelopes. Far, far back in time, the genus, which consists of only one species, branched off, it is believed, from the gemsbok, betook itself to the desert, whence it has never budged, having perfectly mastered the problem of maintaining life for long periods upon a scanty diet when water, so far as man is able to ascertain, is absent.

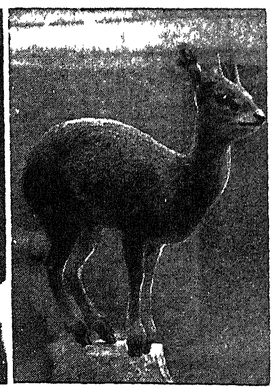
Another desert-dweller is the gemsbok, a big antelope with horns attaining a length of nearly 48 inches in the male, and as much as 45 in the female. The horns of the beisa oryx, though shorter than those of the gemsbok, are very formidable, and it is a point still in dispute whether it was this animal or the white rhinoceros which gave rise to the legend of the unicorn.

So far as bodily outline is concerned, the beisa undoubtedly has it, but it possesses two horns. As to this there is to be noted the fact that a beisa, seen sideways, does appear to have only one horn, and the man who first saw one of these animals so posed might not be concerned to tell of the later view presented, for to do so would spoil a traveler's tale

The beisa oryx, with the Arabian oryx and the white oryx, is restricted to country termed barren, but which the existence of these animals proves to be intermittently fertile. The fact is, much of the African desert is not desert in the sense ordinarily understood. Deserts support an abundant fauna, and it is there that the lion prowls in quest of such animals as we are at present considering. Apart altogether from the oases which are often of very considerable extent, desert conditions vary from swift and transient fruitfulness to the dreary sterility of appearance wherewith the popular conception always associates them We need not go beyond H. A Bryden's description of a season of fertility in the great Kalahari desert "During the brief weeks of rainfall," he says, "no land can assume a fairer or more tempting aspect. The long grasses shoot up green, succulent, and elbow-deep; flowers spangle the veldt in every direction; the giraffe-acacia forests, robed in a fresh dark green, remind one of nothing so much as an English deer park; the bushes blossom and flourish; the air is full of fragrance; and pans of water lie upon every hand. Another month, and all is drought; the pans are dry again, and travel is full of difficulty." But though apparently vegetation perishes from off the face of the earth, the soil teems with bulbous moist roots, that form a nourishing diet for antelopes, and there is a succulent desert melon which is a favorite item of food of these animals.



THE PYGMY DIK-DIK

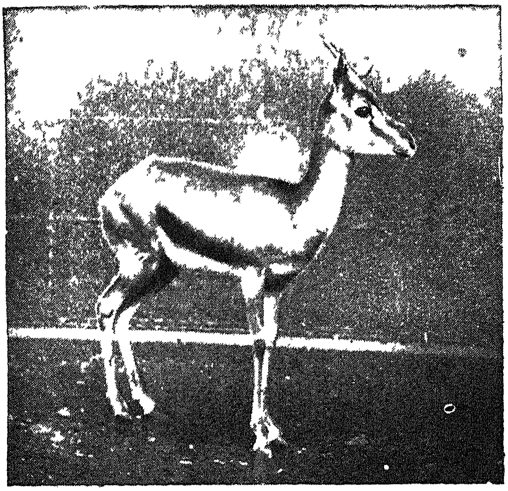


THE AGILE KLIPSPRINGER

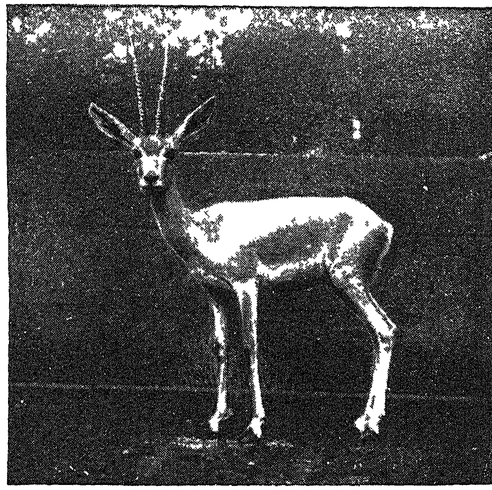
It is a fact that some of the finest of all antelopes exist in the desert, and thither predatory animals have pursued them The existence of antelopes, among other living creatures, obviously modified, both as regards hoof and protective coloration, is cited as an evidence of the antiquity and permanence of deserts The reasoning on this head is not absolutely conclusive The modifications of the antelopes may have taken less time than we suppose Adaptability is not necessarily a process of æons Hagenbeck is not the oldest man on earth, but he once had antelopes and ostriches, lions, Bengal tigers and kangaroos running at large in the snow every winter at Stellingen, near Hamburg, not a bit the worse for their exposure But, whatever the date of the arrival, there are the antelopes of the desert today specially armed to resist carnivorous enemies, no less than for combat, antelope *versus* antelope

Darwin wondered whether the horns of some of these splendid creatures might not, like the most complicated of antlers, have a decorative as well as a defensive object Whatever the case as to that, there is no doubt as to the deadly effectiveness of the weapons, for antelopes of this group are known at times successfully to counter the onslaught of the lion. At such a time the antelope kneels with its head between its forelegs, and at the psychological moment brings up its horns with a lightning swing, which means death if the blow goes home We know that the blow is lethal from the fact that a lion has been found dead, impaled upon the horns of a dead oryx. Gentle even to timidity in normal conditions, these antelopes will at certain times, and especially when wounded and bayed, charge man or dog with boldness and ferocity. Deer hounds have learned to respect the flashing accuracy of the red-deer's hoof.

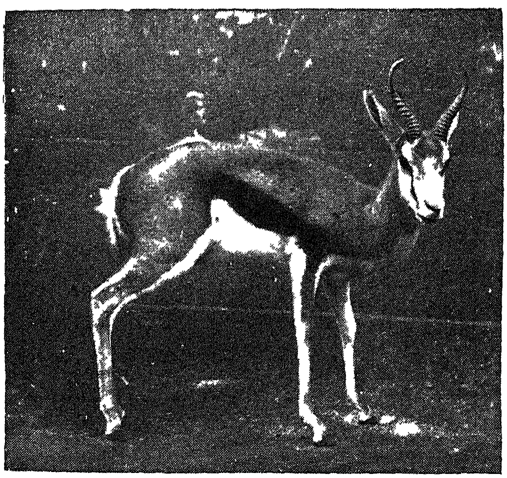
THE ANTELOPE IN SIX VARIETIES



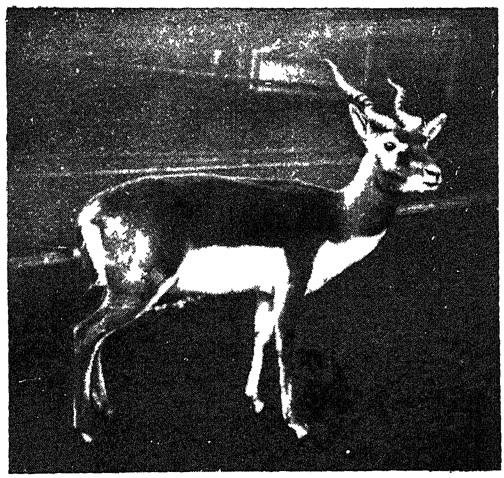
THE RED-FRONTED GAZELLE



THE EGYPTIAN GAZELLE

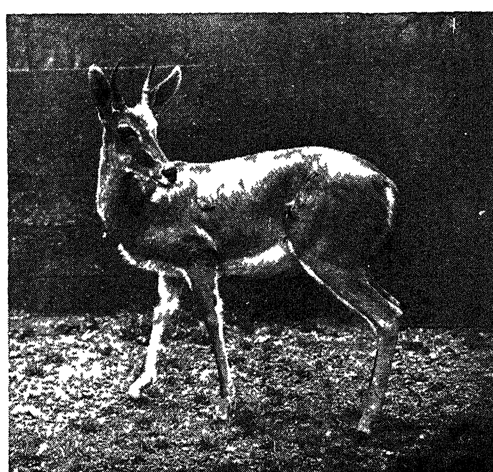


THE AFRICAN SPRINGBUCK



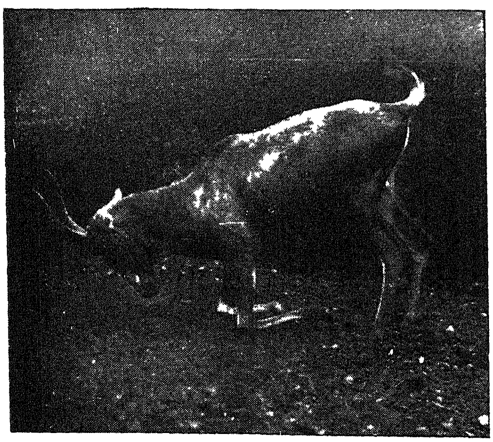
THE INDIAN BLACKBUCK

THE SING-SING WATERBUCK



THE ROE RHEBUCK, OR RHEBOK

But when we come to big, upstanding heavily-horned antelopes like the roan and sable, we have two warriors which match the gemsbok in the potency of their defense. There were three species to this genus, but the blaauwbok, as the Boers named the bluish-colored animal, has been removed from the chapter of the living, and only the sable and the roan remain. The former is the finer of the two species, but both are noble-looking animals, and the sable buck, when wounded, has been known to turn and with three well-directed blows kill as many dogs with its terrible horns. Neither sable nor roan antelopes are numerous, wide as is their range, for a head of either is a trophy of the chase which every hunter in Africa seeks to acquire.



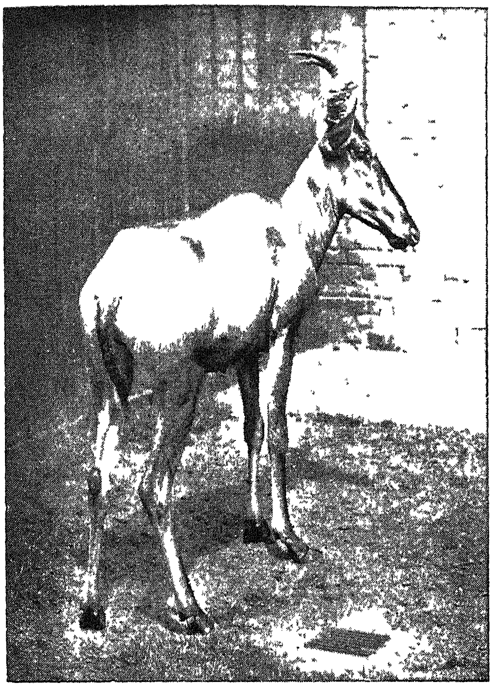
A BLESBOK READY FOR COMBAT

Passing now to the gazelles, we reach a great group of animals classed with the antelopes, from which they differ, however, in that horns are present in both sexes. These horns, often ornate and decorative, are turned to good account against the smaller predatory animals, for even the "dear gazelle" will fight gallantly when pressed, and join, buck with buck, to oppose as solid a phalanx to the common foe as the larger animals of the bovine family. That, however, applies only to animal foes, for, even as the Indians learned in time to look with terror upon the white man and his "medicine" methods of warfare, so the gazelle, in common with the rest of the antelope tribe, will always flee from a man, unless actually cornered.

The springbuck, whose name first comes to mind at the mention of the gazelle, is a biggish member of the group, its height reaching 30 inches in the full-grown male. Springbucks at one time abounded in South Africa in almost incredible numbers, before indiscriminate slaughter reduced their numbers.

"Like greedy locusts, the famishing animals fall upon grass and leaves, grain and other fruits of the fields; where they have passed not a blade is left. The man who comes in contact with them is at once thrown to the ground; a flock of sheep feeding in their way is at once carried off, never to be seen again; a lion which thinks to gain an easy prey finds himself forced to relinquish his victim and to travel with the stream. Unceasingly those behind press forward, and those in front yield slowly to the pressure; those cooped up in the center strive continually to reach the wings, and their efforts are strenuously resisted. Above the cloud of dust raised by the rushing army the vultures circle; flanks and rear are attended by a procession of various beasts of prey; in the passes lurk sportsmen, who send shot after shot into the throng. And so the tortured animals travel for many miles, till at last spring sets in and their armies are broken up."

We must leave the gazelles, and pass to one or two allied antelopes, of which the dibatag, with its forward-inclined horns, and the gerenuk, with a neck like that of a miniature giraffe and hook-like horns curved forward, are notable. Next we have the fine Indian blackbuck, which ranges over a wide area in India, and shows considerable variety in point of size. Then, in the chiru and the saiga, we have two related antelopes, both remarkable for a swollen proboscis. In the chiru this abnormality is less pronounced than in the saiga, in which the nose is so bloated and the snout so pig-like that one cannot resist the impression that at one stage of its career the saiga must have been developing on lines parallel to the tapir. Seen from the front the nose suggests that it has been badly stung by bees. This animal is now confined to the steppes of eastern Europe and western Asia.



ATHLETIC EMOTION — THE HARTEBEEST

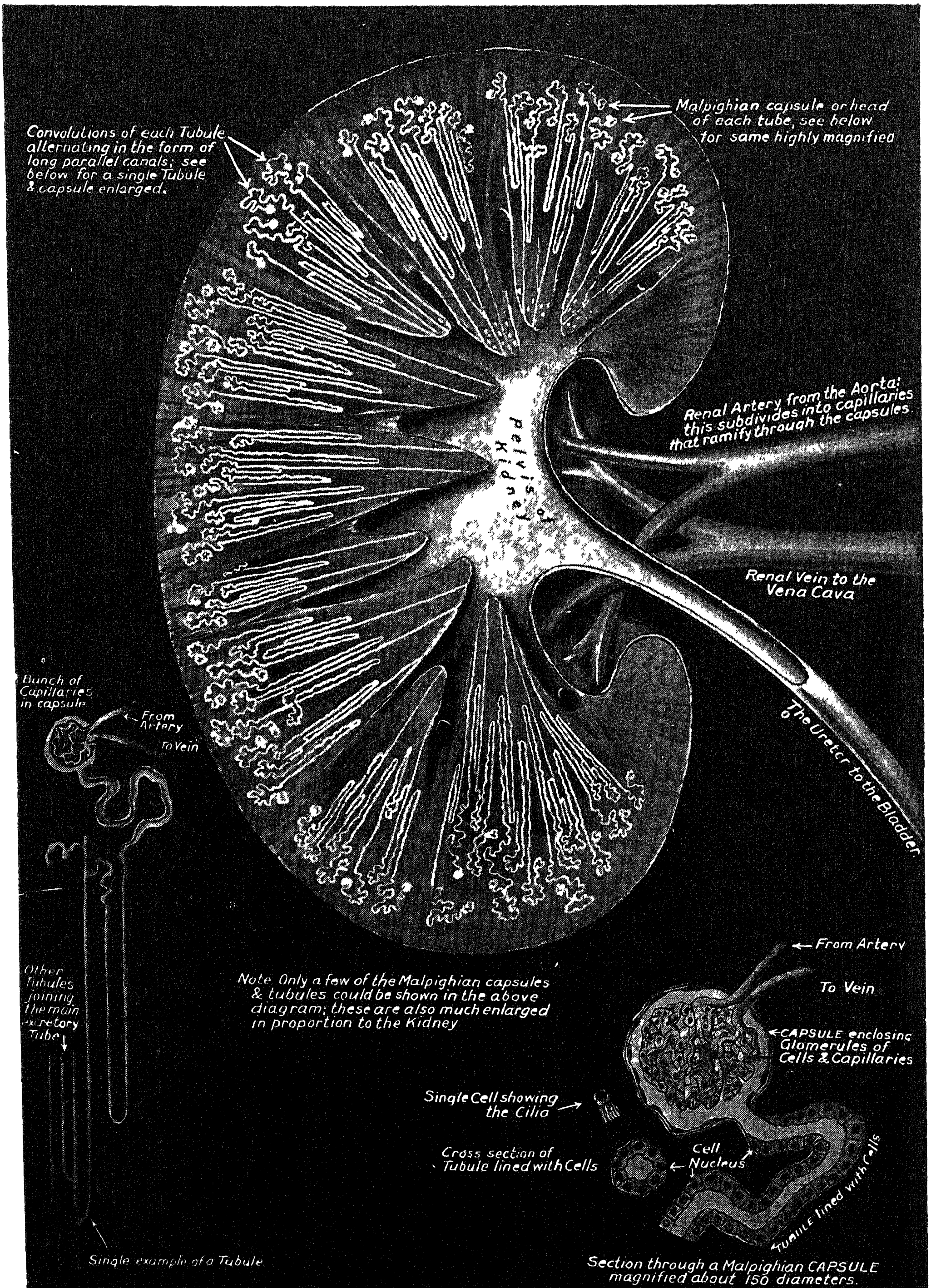
Passing the waterbuck with the note that this is one of two antelopes, the reedbuck being the other, which does not quit the low-lying marshy plains in the rainy season, we reach the delightful little klipspringer already mentioned, wherein the joy of life seems to be embodied. Not even the alert and sure-footed chamois can compare with the klipspringer in the address with which it leaps from crag to crag. Its home is in the stoniest hills, and from the Cape through eastern Africa away up to Abyssinia it may be found at heights as great as eight to nine thousand feet above sea-level. With just a passing reference to the famous rock-leaping rhebok, to the oribis, which, thanks to their protective coloring, only the eye of the experienced hunter can detect, we leave the pygmy antelopes with the observation that among these, including adult animals not more than 12 inches high at the shoulder, are some of the most beautiful little creatures in the whole scheme of living things, gems of beauty and bone and muscle, popping in and out of the grass like hares, and speeding away when startled like birds skimming low.

Our chapter closes with the gnus, a species of which is described in an early chapter of this section. All the gnus, or wildebeests, with their allies, the hartebeests and blesbok, are simply freakish antelopes related to cattle, and more especially to the African buffalo. We have first the white-tailed gnu, next the brindled gnu, or blue wildebeest, then half a dozen species of wildebeest, all powerful, fleet-footed, enduring animals, in which the passion of all antelopes, from elands to springbuck, for expressing emotion by wild and extravagant leapings and caperings, reaches its highest point. Roosevelt during his African trip saw one of the wildebeest leap clear over the back of an adult companion, taking a high ant-hill in its next stride.

But there is some sort of method in what we choose to call the madness of these bucking, leaping gnus, as the hunter discovers who makes too near an approach to one. It would afford five minutes' entertainment in a company of naturalists to take their views as to the animal most to be feared in a zoölogical garden. Probably all would be wrong. The authorities deliberately declare that not the elephant, nor the rhinoceros, nor the hunters belonging to the cat tribe, but the gnus are the most dangerous animals they possess.

THE TREACHEROUS WHITE-TAILED GNU

OUR CHIEF ORGAN OF EXCRETION



These picture-diagrams of the human kidney show graphically nature's marvelous mechanism to rid our blood of its waste materials. Each successive diagram shows a smaller portion of the kidney under higher magnification, thus explaining more clearly the structure of this wonderful organ.

INTERNAL LABORATORIES

A System, Creative and Purifying, that Forms Scavenging Cells, Traps Microbes, Filters Poisons, and Makes Chemical Secretions

GLANDS AND THEIR KNOWN USES

WE now come to the last of the systems concerned with the animal life of the body which are required for the maintenance of the brain. We cannot exactly speak of the glandular system as a unit, in the sense which applies to the circulatory or respiratory system For there are glands of one sort or another in very nearly every part of the body. The brain itself is not a gland, though we may recall the assertion of the German materialist Karl Vogt that the brain secretes thought as the liver secretes bile — as absurd a piece of folly as history records The brain, however, contains two structures which are considered glands of "internal secretion", which structures will soon be taken up Although there are no glands in bone or muscles, we have already seen that the red bone-marrow produces red blood-cells, and it really has as much title to be called glandular tissue as have the lymphatic glands which produce nothing but the white blood-cells called lymphocytes.

Further, even muscles produce certain characteristic products which enter the blood and may affect the rest of the body. Nothing can live without producing certain chemical substances. These must pass into the blood, and practically amount to the secretion of a gland. The point is not academic but practical, for it is one of the great advances of modern physiology to learn that all manner of unsuspected tissues that seem to do nothing are really producing, by their lives, certain substances which they add to the blood as it passes through them, and which, though perhaps exceedingly minute in quantity, may be absolutely essential for life.

Our ideas of a gland must therefore be elastic, but meanwhile we must start with what has long been known We used to consider a typical gland as a collection of cells, with a tube running from these cells, into which, on occasion, they pour a special fluid which has been made by them from the blood. The details in different glands vary, but the principle remains. The active agents are living cells, of high type, usually with large nuclei, which deliberately extract from the blood certain of its constituents, and manufacture special new products therefrom Thus, the albumen of milk is not the albumen of blood, though it is made from the albumen of blood; and this case is typical Now we note that the presence of a duct is not always essential, for the secretion of gland-cells may be added to the blood as it flows through the gland. Thus we learned to recognize the special group of glands or glandular tissues that are now called "ductless", or "glands of internal secretion".

Let us first dismiss the "blood-forming glands", as they used to be called. These are the glands which produce the cells of the blood, and they should not be called "blood-forming", as if other glands did not contribute to the fluid part of the blood. The lymphatic glands, such as are so often attacked especially by tuberculosis in the neck, have tiny vessels, called lymphatics, running to and from them These vessels convey the lymph, but they act as ducts, also, for the young lymphocytes made by the gland, for these young cells pass into the lymphatics that leave these glands, and not into the blood-capillaries Lymphatic glands occur in the neck, in the armpits and groin,

at the roots of the lungs (*i.e.* round the bundle of vessels that pass into the lungs), and elsewhere. They are great traps for microbes, and extremely important in disease, notably in consumption, leprosy and syphilis. In these three diseases, the lymphatic glands are enormously swollen. Microscopic examination shows them packed with the germs that are specific for the disease present.

Just similar tissue is found in the tonsils, and in many curious patches found in the small intestine; also in the back part of the tongue, and in the back of the throat. The glands in the back of the throat—the region of "adenoids"—and the tonsils communicate, through the neck, with the lungs, and are thus of enormous importance in relation, especially, to consumption.

At birth a large and important gland, called the thymus, is found in the upper part of the chest, just below the neck. It is very similar in structure to the tonsils, and because of this structure it used to be erroneously credited with the making of lymphocytes. It normally reaches its greatest size at about the end of the second year of independent life. Then the thymus begins to shrivel up, and at the age of puberty it practically disappears. The function of the thymus is not well known but it seems to be necessary for the proper early growth of the body and to inhibit the development of the sex glands until after the proper growth of the body has been reached. "Sweetbreads" are either the pancreas or the thymus of the calf.

The battle for the purity of the blood that goes on in the spleen

Much more important is the large blood-forming gland called the spleen. There is no ground for the view that this gland is associated with ill-feeling, as when we say, "his remarks were not without a touch of spleen", but there was nothing absurd in the kind of theory which that language expresses. However, as it happens, the spleen in the adult produces only white blood-cells. The organ lies under the left lower ribs, and has a structure very like that of lymphatic glands. It sometimes produces enormous numbers of white cells. In certain diseases it enlarges — notably in malaria and typhoid fever — and while doctors rightly look for this enlargement as a "symptom" of the disease, and while it is much better not to have the disease and therefore not to have the symptom, yet no doubt the enlargement is protective, and means the increased production of white cells to fight the invaders, and probably also a considerable destruction of invaders in the spleen itself We may also find a number of "giant cells" in the spleen, which are clearly phagocytes or "eating cells". Normally, they seem to consume only old and worn-out red blood-cells, but in certain diseases they may play a great part in keeping down the number of parasites in the blood.

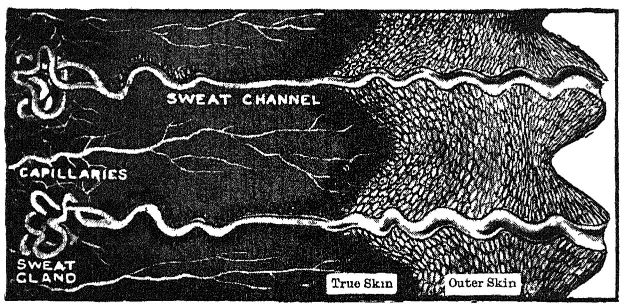
The strange reserves of life, as it calls on different organs for the same functions

We know little of any other functions of this large gland but it no doubt aids in the production of uric acid, helps conserve the iron content of the body, and removes organisms and their poisons. But our predecessors' mistakes regarding the liver and the pancreas and the productive glands should be a warning to us. Function precedes structure, and may employ structure for many purposes. A possible reply to this is that the spleen may be removed, without any ill consequences following, and therefore that it performs no other functions than those named. This is not a good argument, though the experimental physiologists employ it freely. More and more we are learning that there are various functions of the body — by no means all, of course — which are normally performed by one organ or in one way, but can be performed by other organs, or in other ways, when occasion requires. This would not be the case if structures came first, and so made functions possible; but it is the case because life and its functions come first and create the structures they require for the better fulfilment of their purposes. They are not necessarily checkmated when some particular structure fails them, nor does it follow that that structure was useless, for its functions may be assumed by some other organ or structures.

From all these glands there proceed living cells. We pass now to more typical, simpler and humbler glands which produce only chemical secretions. They are to be found nearly everywhere, and we have already encountered many varieties.

Little glands that produce mucus are found in every mucous membrane, such as lines the mouth, nose, throat, trachea, œsophagus, stomach and so forth. Each of these may have special glands of its own, but it always has mucus-forming glands as well, to produce the slimy material, unpleasant to the fingers, which is so pleasant and invaluable a protective, lubricant and antiseptic for the various linings we have named.

The skin produces no mucus, but is covered with glands that produce the secretion called sweat, or perspiration, from the blood, and each hair has glands called sebaceous, which produce *sebax*, an oily material that prevents the hair from cracking. Somewhat similar glands produce the wax of the ear. The salivary and other digestive glands of the alimentary system have already been named.



MAGNIFIED SECTION OF SKIN, SHOWING SWEAT GLANDS AND TWO PORES

Now the microscope has taught us lately a good deal about glandular action. If we take typical gland-cells, say those which produce the pepsin of the stomach, and look at them just before a meal, we find them filled with solid particles which stain clearly with various dyes and show up well under the microscope. The gland-cells are hard at work producing these particles, and so the physiologists absurdly called this the "resting-stage" of the gland. But when food enters the stomach, or when the gland, wherever it be, is appropriately stimulated, all these particles are melted and disappear, so that if we examine the cells after secretion we find them empty of the particles we saw before. Where the business of the glands is to produce a ferment, we find that the solid specks are made of something which is just one stage, so to speak, before the ferment itself. When the necessary moment arrives, the last step is taken, the ferment itself, in liquid and usable form, appears and is poured out of the cell. The substances just before the ferments themselves are now called proferments, and chemical physiology is beginning to find in them and their behavior the key to many of the deepest secrets of the body.

We shall have to return to some of the digestive glands, because of their surprising versatility. But first we must look briefly at the principal glands of excretion. These are the kidneys. Like all other glands, they produce a secretion, but since this is a secretion which is designed to be got rid of, we call it an excretion. In brief, a *secretion* is utilized by the body for the body's betterment whereas an *excretion* is not retained by the body, as it is poisonous and therefore must be eliminated. The bile is an example of both a secretion and an excretion. We have no hold yet of the mere rudiments of physiology unless we well know that excretion is a fundamental necessity of life. Half the business of respiration, we already know, is excretion. The chief excrement in that case is a gas; but the body also produces solids, fortunately capable of solution in water, which equally require excretion. That is principally the business of the kidneys.

They share with the lungs and the skin the duty of removing from the body the water which has partly drained through it, and has partly been made in it by the oxidation of the hydrogen atoms in the compounds of the food. Thus, about fifty ounces of fluid are removed from the blood by the kidneys every day. The quantity varies with many factors, but this is an average figure, assuming the activity of the

skin to have been average also. But in these fifty ounces we find dissolved no less than two ounces of solids — *two ounces of solid matter removed from the blood every day.* This includes some five hundred grains of the remarkable compound called urea, and about ten grains of the still more celebrated compound called uric acid, crystals of which we find in gouty joints.

The kidneys among the most complicated and wonderful of our organs

The kidneys are among the most wonderful organs in the body of man. In the lower animals such as the worms, which are made of a number of similar segments, strung together, each segment has a pair of kidneys. In ourselves, each kidney is a single organ, but its structure in the embryo shows that it has been developed by the union of more than a dozen separate but similar glands. Its structure is very complicated, but essentially consists of a large number of very long coiled tubes, lined with cells. Each tube begins in a little cap, supplied by a bunch of capillaries, and here the water of the blood seems to filter through, probably in an almost mechanical way. But the cells that line the long tube, through which the water drains, are most of them deep, well-nucleated, secreting-cells, and it is thought that these cells extract the urea and so forth from the blood, besides producing, from certain constituents of the blood, compounds altogether new.

The action of these cells has long been regarded as mechanical, but we have every reason to suppose that it is largely vital, involving a genuine selection from the blood of certain substances, and a scrupulous retention of others. It is only when the kidney-cells are out of order that they permit the slightest trace of the precious proteins of the blood to leak away; and the discovery of the connection between this leakage and disease of the kidneys was made by the English physician, Richard Bright, after whom Bright's disease was named. Perhaps the least common feature of this disease is pain in the loins, by the way, notwithstanding some copious public instruction to the contrary.

On the whole, however, the kidneys are more filters than anything else. The filtration is essential to life, ridding the blood of a great many waste-products of life, and of the waste coloring-matter of broken down red-yellow cells; but it is probably less remarkable, as a chemico-vital feat, than many, less familiar, which are achieved by other glands. To these we must pass, though the physiologist is bound to observe that modern man abuses few of his organs so constantly and carelessly as his kidneys by what he eats and drinks, and that there is no organ which suffers more frequently or disastrously from causes which are well within the control of common sense and sound physiological habits of life.

How the pancreas performs other services than production of the pancreatic juice

The pancreas and the liver have already been described as appendages of, and contributors to, the alimentary system. They are much more, and in certain cases of illness we find sugar in the secretion of the kidneys, and may naïvely suppose that this diabetes, as it is called, is due to disease of those organs. They are found to be healthy, however; and research has shown that all they do is simply to remove from the blood the excess of sugar which it contains in this disease. The blood must always contain a proportion of sugar in health, for distribution to, and combustion in, the muscles; but if that proportion becomes injuriously high, the kidneys do their best to control it. We have found that the trouble is often due to the pancreas.

This organ contains, throughout its substance, a number of little clumps of cells obviously not the same as those, the great majority, which produce the pancreatic juice, and which show the changes already described before and after secreting it. These special cells seem to do nothing. But we now have every reason to suppose that they produce an "internal secretion" that never reaches the pancreatic duct and the bowel, but is absorbed by the blood as it passes through the pancreas, and *makes possible the combustion of sugar.* We have seen the pancreas produce several digestive ferments, invaluable in the bowel.

But here is another ferment, more profoundly digestive, which makes possible the combustion of sugar in the ultimate and "secondary" digestion — the digestion of their food by the living tissues of the body. Hence we find that removal of the pancreas from the body produces rapid and fatal diabetes, and we learn, or should learn, to be very careful in supposing that the discovery of one function, or ten functions, however important, of any tissue or organ of the body, necessarily completes the tale of its powers.

The production of bile only one of the many functions of the liver

More striking still is the case of the liver. The obvious function of this large gland, far and away the largest in the body, is that it produces bile. Bile is of some use in digestion, favoring the turning of fats into an "emulsion", which is more easily attacked by the fat-splitting ferment from the pancreas. Bile also favors the onward movements of the bowel. But it contains no digestive ferment, and must be looked upon as essentially an excretion. It is not a particularly poisonous excretion, however, for quite large quantities of it may pervade the body for months or years in jaundice with far less injury than might be expected.

It seems to owe its color to the remains of old red blood-cells, which are partly broken down in the liver. It has a bitter taste, to which we allude when we talk of "gall and wormwood", and, since it is useful in digestion, it is not poured continuously into the bowel, but is stored up in what is called the gall-bladder, a small receptacle lying just under the liver. If the bile is stagnated here under irritation, "gall-stones" may be produced which often require the kindly aid of the surgeon for their removal.

But this obvious biliary function of the liver, which long prevented the physiologists from looking for any more, is really only one of many. This is indeed a marvelous organ, with so many important functions that we may well assent to the double meaning of the admirable jest: "Is life worth living? It depends upon the *liver*." More remarkable still is the fact that these numerous, diverse and subtle functions are performed by an organ which, however huge, contains practically only one type of cell. If it had contained eight or ten notably different kinds of cell, physiologists would long have hunted about to discover a function for each type of cell, on the view that "structure comes first", and then discharge functions. They could not realize the infinitely more profound idea that "Life does what it needs, as it pleases, making one structure or many when it will."

The liver-cell, a simple enough thing to look at, which discharges eight or more functions, is, after all, a mere pedant compared with the amœba, which discharges all the functions of life, including sensation

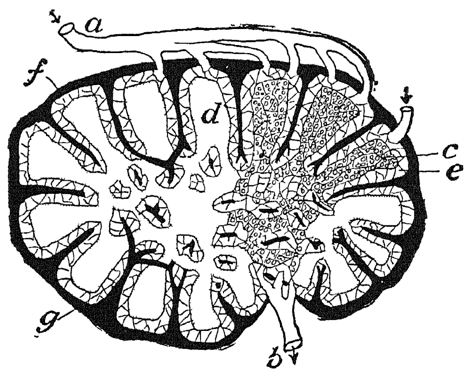


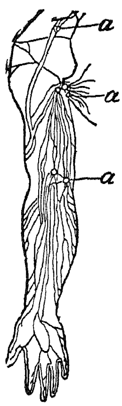
DIAGRAM OF A LYMPHATIC GLAND

The lymphatics enter the gland at *a*, pass through *e* and leave at *b*; *c* is lymphoid tissue; *d*, cortical substance; *f*, fibrous capsule surrounding the gland, and sending divisions into *g*, the substance of the gland.

and movement, though it is only a single cell. We must insist upon this, which is one of the most important generalizations of modern physiology; and we may see its supreme significance when we reach the brain, and have to decide whether the structure called brain was evolved first by chance and natural selection, and discharges a function called mind, which is destroyed when the brain is destroyed, or whether mind came first, and created the structure called brain for its better expression. Perhaps now we see that the just physiological understanding of the relation between structure and function, in the liver and the brain as well, determines the verdict of science on the question of immortality. To this theme we must return.

Now let us see what further functions the life of the body thinks fit to perform through the medium of the liver-cells.

We have named only one as yet. Secondly, the liver produces the substance urea, from various compounds that circulate in the blood, having been derived from the breaking down of the proteins in the food. This is a very serious business, for we have just seen that about five hundred grains of urea leave the body daily by the kidneys, and a small quantity also leaves it by the skin. But the kidneys and the skin merely remove what the liver has made; and in the absence of this function the body would soon be killed by the accumulation of its own products, which only the liver can dispose of.



LYMPHATIC VESSELS IN THE ARM
a, Glands.

This second function of the liver involves oxidation or combustion — the production of heat — so that the blood which leaves the liver is markedly warmer than that which enters it, and thus the liver helps to maintain the temperature of the body. This is a very useful function, but as it depends upon the last we need not count it here. Merely we note that, in virtue of its bile-forming function and its urea-forming function, the liver is evidently the chemical destructor of the body. All manner of rubbish, living and dead, such as old red blood-cells, and the products of the use of the food by other tissues, are sent there to be destroyed; and in the process of destruction the clever liver contrives also to keep the body warm.

But this is no ordinary destructor, for it is capable of carefully sorting out anything really useful from what is sent to it for destruction; and, having sorted out what is useful, it acts as a storehouse, doling out to the blood thereafter just as much as may be required. We may call this a third function, though it clearly has two aspects. Red blood-cells contain a good deal of iron in their hæmoglobin, as we know. But there is only the merest trace of iron in the bile.

The coloring matter of the bile is of the hæmatin derived from hæmoglobin, *minus* its iron. Bile-pigment is thus practically iron-free hæmatin The iron is carefully stored in the liver-cells when the bile is sent away, and is afterwards doled out to the blood, in quantities which the blood can hold, to go to the red bone-marrow, where new red blood-cells are being formed, and so begin the round again.

This is a rather pretty example of one of the many and subtle economies of the living body; and the physician may be disposed to remember it when he has to deal with anæmia, and contrasts the huge doses of iron that are alone effective with the very tiny daily loss of iron from the body. Plainly it is not an easy matter to get iron into the blood, and that is why the liver is so careful with it, and why even thirty grains of iron salts may be put into the bowel daily in order to get a grain or two into the blood.

There is no doubt that in some animals, and probably in some human individuals the liver also stores fat, and serves it out in cold weather, as when an animal hibernates. Before birth, the liver is an important factory of both red and white blood-cells.

Claude Bernard, the great French physiologist, found that the liver has the most important function of storing the glucose, or sugar, which reaches it from the bowel, where it has been formed by the digestion of the starches and other sugars of the diet, and of changing it into a substance called glycogen, or "animal starch". As such it is stored in the liver; and, when and as the muscles and other parts of the body require it, the liver turns it into glucose again, and serves it out to the blood.

There is some evidence to show that the liver produces an "internal secretion" which may prevent the formation of malignant growths in the body.

Lastly, we have found that the liver is the great filter of food-poisons. That, we now realize, is why the liver is placed on the route of the blood back from the bowel to the rest of the body. All the blood from the bowel has to run the gantlet of the liver first; and large quantities of unsuitable matter, picked up by the bowel, are rejected by the liver and poured into the

bile, while the blood, free of this matter, passes on to the rest of the body.

The endocrine glands, or glands of internal secretion

We now come to the group called the endocrine glands, or glands of internal secretion. They include the pituitary gland, the thyroid, the parathyroids, the pancreatic islets of Langerhans, the adrenals, the sex glands and the thymus, described on page 1712. The endocrine glands secrete hormones, chemical substances that pass from the glands into the blood. These hormones are carried to different parts of the body and help to regulate its activities.

The pituitary gland is the master gland of the endocrine system

The pituitary gland, also known as the hypophysis, is no larger than a child's marble. It is shaped somewhat like a baseball-catcher's glove, with a ball in its center. The anterior lobe of the gland is the glove; the posterior lobe is the ball. The pituitary gland is located at the base of the brain and is attached to it by means of a short stalk. It fits snugly into a protected cavity of bone, known as the *sella turcica* (Turk's saddle).

The pituitary gland is the master gland of the endocrine system; it controls the functioning of the other endocrine glands through certain special hormones secreted by the anterior lobe. Without these secretions these glands would either cease to function or would function very inadequately. The anterior lobe also secretes a growth hormone that promotes anabolism — that is, the building up of protoplasm.

The hormones produced by the posterior lobe of the pituitary gland are also extremely important. They act upon smooth muscle and upon the pigment cells and they affect blood pressure. The hormone called pitressin causes small blood vessels to contract and brings about active movement of the intestinal muscles; it also regulates the amount of water in the body.

If the pituitary gland does not function adequately, the sufferer is extremely sensitive to cold; he lacks appetite; he is apt to fall victim to infection. If the gland is excessively active, it may bring on acromegaly, a disease that causes enlargement of various parts of the body. Persons affected by acromegaly before normal growth has been completed become outlandishly tall; most circus giants are recruited from their ranks. If the disease sets in after puberty, the skull, jaws and ribs grow disproportionately large, while other bones become very thick. The result is a grotesque individual with an enormously large head and thick limbs.

The thyroid gland is located just below the larynx

The thyroid gland is a good deal larger than the pituitary gland. It consists of two lobes located on either side of the trachea, or windpipe, just below the larynx. The gland secretes the thyroid hormone, which stimulates the oxygen consumption of all body tissues. Thyroxine, the essential part of the thyroid hormone, contains iodine, which is supplied in minute quantities by water and various articles of food.

In the condition known as hypothyroidism, an inadequate amount of thyroid hormone is secreted. The patient has a slow pulse and low blood pressure; he is apt to be drowsy; his mental processes are slow. This condition is treated by administering thyroid hormone. In hyperthyroidism the thyroid is unduly active. The sufferer is nervous, excessively energetic and tends to have insomnia. His pulse is very rapid; he is apt to perspire freely. This condition may be relieved by the removal of most of the thyroid, leaving only enough to maintain the normal functioning of the gland. Certain sulfur compounds have proved most effective in treating hyperthyroidism.

A goiter is an enlargement of the thyroid gland

If the diet does not include enough iodine, the thyroid, in an effort to produce more hormone, becomes larger and more active. In time a considerable enlargement of the gland develops; this is called a goiter. The condition may require surgical treatment; but often the addition of small

amounts of iodine to the diet will bring about the disappearance or the reduction of the swelling. It has been found that minute quantities of iodine in table salt will effectively prevent goiter.

In certain individuals the thyroid fails to develop. Such persons, known as cretins, remain dwarfed mentally and physically. If cretins are treated from earliest infancy with adequate amounts of thyroid extract, they develop remarkably well. Unfortunately, if the treatment is discontinued, they revert to their former condition.

The parathyroid glands regulate the calcium content of the blood

There are four parathyroid glands, each about as large as a third of a grain of corn. They are located at the upper and lower ends of each lobe of the thyroid gland. The parathyroids assist in the regulation of the calcium content of the blood.

If there is a marked drop in the amount of calcium in the blood, the muscles become tense at the slightest stimulus. If the condition is not suitably treated, a general tightening of the muscles (tetany) occurs and this may be fatal. Calcium, administered intravenously, relieves the condition; so does an extract of the parathyroid gland. Effective treatment can also be provided by a synthetic substance called dihydrotachysterol, related to vitamin D.

Certain tumors on the parathyroids may cause these glands to become excessively active, resulting in a marked increase in the calcium content of the blood. The blood becomes thick and clots easily; the kidneys are filled with calcium deposits, causing kidney failure and high blood pressure; stones may form in the kidney or bladder. Removal of the tumors cures such cases, unless too much damage has already been done.

The pancreatic islets of Langerhans secrete insulin

The islets of Langerhans are clusters of granular cells, scattered in the digestive organ known as the pancreas. These islets secrete the hormone called insulin, which makes it possible for the cells of the body to utilize glucose, a form of sugar. If the production of insulin is inadequate, the glucose accumulates in the blood and passes out in the urine as a waste. To make good the loss of glucose, the body burns fat; it also converts proteins into glucose, which cannot be used by the body because of the insulin deficiency. The patient becomes seriously weakened; a comparatively slight injury or infection may prove fatal. This condition is known as diabetes.

Before insulin was isolated in 1921 by Frederick G. Banting and his assistant Charles H. Best, persons suffering from diabetes had a very limited life expectancy. This dismal state of affairs changed almost overnight when doctors began to treat patients with regular injections of insulin. Today diabetics can look forward to a normal life as long as the insulin treatment is continued.

The adrenal glands are located above the kidneys

There are two adrenal glands, one just above each kidney. Each consists of a central portion, the medulla, and an outer portion, the cortex. The medulla secretes a hormone called epinephrine, or adrenaline. A sudden wave of fear or rage leads to a release of epinephrine to the blood. This stimulates the nervous system so as to marshal up the individual's reserve power for whatever emergency may be at hand.

The adrenal cortex helps to regulate the salt balance of the body; it also helps the body to utilize sugar and protein. Several hormones bring about this result; one of them is 17-hydroxy-11-dehydrocorticosterone, better known as cortisone. Cortisone derived from the adrenals of cattle has proved beneficial in the treatment of arthritis and other diseases.

The sex glands are the testes in the male and the ovaries in the female. The testes produce sperm, or male germ cells, and testosterone, the male hormone that keeps the reproductive organs functioning normally. The ovaries supply the ova, the female germ cells, and manufacture the female hormones, estradiol and progesterone.

CLOTHES AND LAUNDRY REAGENTS

The Injury Caused by the Indiscriminate Use of Chemicals

LAUNDRY SOAPS AND WASHING COMPOUNDS

THE first step in the successful laundering of fabrics is to know the composition of the detergents, water softeners, laundry blues, etc., and how these materials will affect the clothes. Apart from the injury caused by the careless or indiscriminate use of chemicals to remove stains and to bleach, the composition of the soaps, soap powders and "washing compounds" is responsible for much of the discoloration and even destruction which is commonly observed. Of course, if the soap — even pure soap — is not rinsed away thoroughly, but is allowed to dry in the fabric, it will tend to turn the clothes yellow.

Possibly there is no product on the market today which can have such a varied composition as "soap", and the number of such soaps which are usually advertised as pure, and recommended to wash the most delicate fabric without injury, distracts the buyer. Chemically, soap is "a mixture of the sodium or potassium salts of the fatty acids of relatively high molecular weight". In actual practice, the salts of abietic acid ($C_{44}H_{65}O_5$), which are obtained by treating rosin (colophony) with sodium or potassium hydroxide are also present in some soaps; and though not chemically classed as soaps, they act like soaps in so far as they make a lather with water, though they may have little cleansing power. In addition to true soap and rosin soap, some water is always present, and small amounts of impurities and by-products of manufacture. For various reasons certain other substances are frequently added, among which may be mentioned sodium carbonate, sodium borate, and sodium silicate, which, it is claimed, help to soften the water and make the soap more detergent, but which in reality also make a hard soap even when an excessive amount of water is present, and must therefore be looked upon as adulterants irrespective of the detrimental effect of at least two of them, when present in any quantity, on the fiber. Sand, pumice powder, infusorial earth, china-clay, and talc are also sometimes added to soaps, but are really filling materials and quite undesirable in laundry soaps. It must also be remembered that all these materials are cheaper than soap and that it is not economical to purchase them at soap prices.

The raw materials from which soaps are manufactured are, with the exception of rosin, animal or vegetable fats and oils. These are glyceryl esters of the fatty acids, and when they react with sodium hydroxide (NaOH) or potassium hydroxide (KOH) the corresponding sodium or potassium salts of the fatty acids are generated, together with glycerol (glycerine). This process is termed the "saponification" of the fats and may be represented in the following way:

Fat + caustic soda or potash
$\longrightarrow$ glycerine + soap.

Since the natural fats and oils are mixtures of the glycerides of several fatty acids, the product resulting from saponification must be a mixture of the corresponding sodium or potassium salts. Taking olive oil as an example, the acids present as glyceryl esters are oleic, palmitic and linoleic acid; consequently the soap made from olive oil must be a mixture of

the salts of these acids, namely, sodium oleate, sodium palmate, and sodium linoleate, if sodium hydroxide has been used. Various fats are used in making soap by this process, but the principal ones are tallow, olive oil, palm oil, cottonseed oil, castor oil, coconut oil, and palm-nut oil, mainly compounds of the acids mentioned.

The commercial preparation of soap

In the commercial preparation of soap by the saponification method (the method most commonly used), the product obtained after the reaction is complete is a mixture of crude soap, water, glycerin and the various impurities that were present in the original ingredients. If more fat or more lye has been used than can be acted on chemically, the excess will be mixed with the other products. To remove the impurities, common salt is added to the pan, which causes the soap to "grain" out on the top, and, as it cools, form a hard cake. The lower layer is removed and from it the salt is recovered to be used again, and the glycerin, being a valuable by-product, is separated. The crude soap is then reboiled with lye, and for yellow soaps rosin is introduced.

The lye must be drawn off after boiling

Boiling is continued until the soap is of the correct consistency; then the lye is drawn off. Water is added until the soap loses its granular appearance, after which it is allowed to settle for several days. The soap from the top is then pumped into a stirring device, and with it are mixed the various materials such as sodium silicate, sodium carbonate, sodium borate, talc and other fillers. After stirring, the soap is run into frames or large sheet-iron boxes with removable sides and allowed to solidify; finally it is cut and packed.

Soap always contains a certain per cent of water, the presence of which, if not excessive, cannot be considered an adulterant. If the soap is thoroughly dried, it can be shaved into fine chips and dried again till only about 10 per cent remains. In the specifications of the United States Bureau of Standards the amount that is contained in a laundry soap should not be more than 20 per cent.

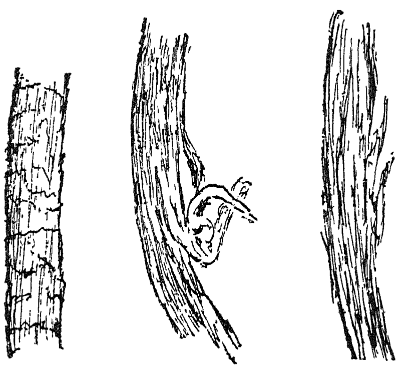
The use of rosin in soaps

Although rosin, if not used in excessive amount, is not considered by manufacturers to be an adulterant, but rather to improve the soap, its continual use in laundry work is not very desirable. There is no doubt that the use of rosin in making soap promotes the lathering properties of the product. But it has been undoubtedly proved that linen and cotton goods repeatedly washed with soap containing rosin become markedly more tinged with a yellowish brown hue than portions of the same goods washed with soaps free from rosin. The difference is quite noticeable even when the rosin acids do not exceed 5 per cent of the total fatty acids of the soap, and the higher the percentage of rosin, the more marked the effect. Large amounts of rosin also make the soap sticky and too easily soluble, and therefore wasteful, unless rehardened by the addition of sodium silicate or one of the other compounds previously mentioned. The characteristic rosin curd that also forms with hard water sticks to the clothes and is difficult to rinse away. If any traces of the curd are left, the clothes are apt to take a yellowish tinge on drying. The United States Bureau of Standards recommends not more than 15 per cent rosin in a high-grade laundry soap, not more than 25 per cent in an ordinary-grade laundry soap, and none at all in chip soaps.

Materials that are insoluble in water

The addition to soaps of materials that are insoluble in water can be looked upon as an adulteration to give added weight and to cheapen. The United States Bureau of Standards has taken cognizance of this kind of adulteration. It has specified that matter insoluble in water shall not exceed 0.1 per cent in special-grade laundry soap, and none at all in soap powders.

The addition of naphtha or other grease solvent to soaps is made with the idea that this substance will dissolve any grease which is holding the dirt particles to the fibers and liberate it so that it will be removed by the water. Since at a temperature below the boiling-point of water these grease solvents are volatile, they are lost if used in the boiler or with very hot water and also on exposure to air. It has also been shown that washing compounds containing trichlorethylene — a grease solvent sold under the name of "Westrosol" — will produce a yellow tint in fabrics, so that their use is to be avoided. Soaps containing chlorine compounds for bleaching purposes are undoubtedly bad, as the destructive effect of the chlorine is in-



A B C

WOOL FIBER

A, before treatment.
B, after treatment with .05% solution of caustic soda.
C, after treatment with 1% solution of sodium carbonate.

creased by the prolonged action at a high temperature. It is also wasteful to attempt to bleach with the chlorine compound in the soap solution, as soap itself is attacked by the hypochlorite and consequently more soap will be required than would be used otherwise.

The desirability of having any other ingredients, such as caustic soda, carbonates, borates and silicates, present in "soap" can now be discussed. It is not usual to find any free caustic alkali in laundry soap, except perhaps in some freshly prepared soft soaps, or in very poor quality soaps. Should any be present in a freshly prepared soap, it will gradually be changed to sodium carbonate by the action of the carbon dioxide in the air. It has been shown that even so dilute a solution of caustic soda as .05 per cent strength will have some action on wool. It will render it harsh, brittle and shrunken. In the figure on the left *B* shows something of this effect. A 1-per cent solution at 90° F. will completely destroy wool in a very short time. Silk will also be easily affected by caustic soda.

It must not be supposed that all the fibers in any fabric will suffer to the same extent as is indicated in the diagram, but this will give some idea of what will be the effect of prolonged or repeated action of soap containing small amounts of the alkali, or of other alkaline salts such as silicate or phosphates which hydrolyze in water and so produce sodium hydrate. Sooner or later a similar result will follow as the weakened material is subjected to wear and tear.

The action of sodium carbonate on wool and silk is decidedly less than the action of caustic soda, but even a 1-per cent solution will cause felting of the wool, and microscopic examination will show the fibers to be much twisted and broken (see the figure, Exhibit *C*). Soon the material will lose its natural elasticity and be decidedly yellow in color.

Solutions of borax have a far less destructive action on these fibers than the solutions of carbonate, but wool may be rendered harsh and impoverished by the continual use of a strong solution. A very dilute solution of borax will materially assist in the removal of grease from wool. The effect on silk is much the same as on wool, borax having the least effect of the three compounds under discussion.

The action of dilute solutions of sodium carbonate on cotton and linen is less harmful than on wool and silk, though hot, strong solutions will discolor cotton somewhat and linen more; and cotton can be destroyed by prolonged boiling in a very strong solution. It may appear, therefore, that no danger is to be apprehended from the use of soaps containing considerable amounts of sodium carbonate in washing cotton and linen goods; but while a single treatment at a moderate temperature followed by thorough rinsing may have no

bad effects, the constant use of hot solutions will. Even though the solution be dilute, if imperfectly rinsed — and this is a very common fault in laundry work — the alkali will concentrate on drying, and under the hot iron will very speedily produce a decidedly yellowish tinge. The color of the material will not be so clear; the threads become a little roughened and the formation of lint is increased; even if the damage is not excessive there will be *some* weakening of the fiber. The color effect on linen is more decided than on cotton, and the weakening effect may speedily lead to disintegration. The effect is worse if hard soap containing carbonate is used and rubbed on the fabric, as here there may be decided concentration.

The effect on all the fabrics of sodium silicate is much worse than that of sodium carbonate, since a certain amount of sodium hydrate is produced by the action of the water — the effect of which, even in dilute solution, has been discussed. In addition, silicic acid is also produced and deposited in the fibers, and with hard water insoluble calcium silicates are formed. Cotton and linen threads probably become brittle owing to these encrusting substances which do not allow the fibers to yield to a bending strain, and the threads are weakened owing to disintegration caused by the loosening up and separation of the fibers composing the thread.

The use of soap or soap products containing free sodium silicate is therefore to be condemned. The admixture of sodium carbonate with the soap is also to be avoided in laundry work, as it may be in excess. The admixture of sodium borate with the genuine soap is less harmful; but since the amount present may also be in excess of the small quantity which would be effective in helping to soften the water or to remove grease, and because the repeated use of a strong solution will have some harmful effect on wool, it is better in this case also to use pure unadulterated soap, and add the borax separately in the amount necessary to soften the water or to help in the detergent action. Moreover, while carbonate can also be used for this purpose in preparing the soapy lather for cotton and linen, caustic soda (lye) or sodium silicate should on no account ever be used. The U. S. Bureau of Standards recommends that the free alkaline salts (including carbonates, borates, and soluble silicates) in a special grade laundry soap should not exceed 1 per cent (reckoned as carbonate); in an ordinary grade laundry soap not less than 2 per cent, or more than 6 per cent; and that not more than one-half of the alkaline salts shall be in the form of sodium silicate. In a chip soap it is recommended there shall not be more than 0.5 per cent of free alkaline salts. This would make the amount of free alkali in the water very small indeed.

Soap powders are usually mixtures of some soap with varying and often quite large proportions of carbonate, and sometimes sodium silicate and borate. The U. S. Bureau of Standards specifies *not less than* 40 per cent of sodium carbonate shall be present; and the carbonate and anhydrous soap together shall be not less than 75 per cent. It is therefore evident that soap powders are altogether undesirable for laundry work if the fabric is to be conserved. The economic value of soaps containing these admixtures is discussed later.

While the large consumers of soap have been able to purchase under definite specifications for many years, the average laundress has no way of determining the value of the soap she buys except by trial, and cannot easily detect impurities, adulterants, and undesirable ingredients. The following simple tests can, however, be carried out and will give some idea of the composition.

(1) To detect rosin, examine the color of the soap. Rosin soaps are usually yellow or even brown and very often feel sticky and have a characteristic odor.

(2) To detect sodium carbonate, take a solution of soap in water and add a few drops of vinegar; effervescence indicates the presence of a carbonate.

(3) To detect insoluble filling, examine the solution of the soap prepared in test 2. On standing a few minutes, the filling will sink to the bottom of the vessel and will readily be seen, especially if the vessel is of glass.

(4) To detect borax, dissolve some finely divided soap in a little methylated spirit by shaking well in a small bottle, which can be heated by immersing in a pan of hot water (care being taken to keep this away from a bare flame, as the vapor is inflammable). The soap will dissolve, but carbonates, borates and silicates, together with any insoluble filling, will be left undissolved. Allow the residue to settle and pour off the liquid. Repeat this several times until all the soap is dissolved away from the other materials. Then add hot water to the residue in the bottle. The alkaline salts will dissolve and the presence of any insoluble material confirms test 3. After settling again, pour off the clear water solution, save part for test 5, and to another portion of it add a little hydrochloric acid.[1] Dip into the solution a piece of turmeric paper[1] and dry carefully without burning it. If it turns pink, it indicates the presence of borax. If when the hydrochloric acid is added, there is effervescence, this confirms test 2 for carbonate.

(5) To test for silicate. The clear solution saved from test 4 may contain silicate as well as carbonate and borate. If silicate of soda is present, unless the solution is very dilute, it will give a white gelatinous precipitate if to it is added a solution of sal-ammoniac[1] (ammonium chloride). A similar gelatinous precipitate may also have been formed when the hydrochloric acid was added to test for borate and carbonate.

The writer has found that as far as chemical analysis indicates, the chip soaps are on the whole superior to the hard bar soaps sold to the housewife, — the greater majority of them containing no impurities or fillings, while there are very few hard soaps (except Castile soaps) which do not contain either rosin or alkaline salts. As far as their actual detergent properties go, there is at present no accurate test which can be applied to grade them. Experience shows, however, that most of the pure soaps are good detergents.

[1] Muriatic or hydrochloric acid, turmeric paper and sal-ammoniac can be obtained from any drug store.

A rough comparative test of the economic value of soaps can be made in the following way. Suppose that the reader has five samples of soap chips which she believes to be pure, the net prices of which are:

(1)	$10\frac{1}{2}$ ounces for 19 cents
(2)	16 ounces for 23 cents
(3)	$4\frac{3}{4}$ ounces for 13 cents
(4)	16 ounces for 27 cents
(5)	$13\frac{1}{2}$ ounces for 33 cents

These figures convey little information as to their relative values. If, however, the weights obtained for 5 cents are worked out from these figures, we get the following:

(1)	2.8 ounces for 5 cents
(2)	3.5 ounces for 5 cents
(3)	1.8 ounces for 5 cents
(4)	3.0 ounces for 5 cents
(5)	2.0 ounces for 5 cents

This indicates that sample 2 is the cheapest and sample 3 the most expensive of the five. But since they may contain different amounts of water, this must also be taken into account and will make some difference if there is excessive water in any one of them. If 5 cents' worth of each sample is spread out on a saucer and the samples are all placed in a warm (not hot) oven and left for several hours, a large proportion of the water will evaporate and the residues may be considered to be "true soap." Suppose that on reweighing, the figures obtained are: (1) 2.7 ounces, (2) 3.4 ounces, (3) 1.6 ounces, (4) 2.9 ounces, (5) 1.7 ounces. This would indicate that sample 5 contained more water than the others and there was only 1.7 ounces of true soap for 5 cents. This would also indicate the fact that samples 3 and 5 are about equally expensive and that sample 2 is still the cheapest.

There are a large number of soap powders and soap "granules" on the market. All those examined by the writer contain sodium carbonate in proportions varying from about 30 to 60 per cent, and a higher moisture content than any chip soap The real value of such a soap powder is shown by the following figures:

If 5 ounces of the powder costs 9 cents, the weight obtained for 5 cents is 2.8 ounces. If this contains 43 per cent true soap, only 1.2 ounces true soap is purchased for 5 cents; and if it contains 29 per cent "soda," reckoned as carbonate, this is equivalent to 2 3 ounces washing soda. Now 1.2 ounces of a pure chip soap can be bought for 1.9 cents (sample 2 mentioned above) and 2.3 ounces washing soda for about 1 cent, so that anyone making the same mixture from pure soap and washing soda would save at least 2 cents on 3½ ounces of the homemade mixture. In addition, the mixture would be more effective than most soap powders, because of the very large proportion of soda to soap.

An exceedingly expensive "magic" soap powder

Another soap powder that "cleans like magic" everything from "carpets and rugs" to "paint and enamel," "bleaches the laundry and takes shine from clothes" was bought by the writer for 25 cents. The contents of the package weighed 2 ounces, making the price $2.00 per pound. Its composition proved to be less than one-half soap, the remainder being mostly carbonate and water with a small amount of borax. This soap powder was colored with laundry blue. The total cost of the ingredients would be certainly less than 20 cents per pound.

Washing compounds that are merely soda

Washing compounds recommended for washing everything from greasy dishes to the finest laces without the slightest injury, are as a rule merely "soda" in some form or another, and they contain no soap. They may be a mixture of sodium carbonate and bicarbonate with varying percentages of water, and if in solid form are perhaps held together by a little starch or gum. Some of them recommended particularly for laundry work contain a little laundry blue — either aniline or ultramarine. One well-known washing compound is pure trisodium phosphate. The bad effect of any of these substances, used in quantity on clothing and imperfectly rinsed out, can be very readily demonstrated and it has already been referred to. The cost of these compounds is also out of all proportion to their value. This is illustrated in the case of one of them that is sold at the price of 25 cents for less than 4 ounces, making the cost practically $1.00 per pound for some form of "soda."

Hardness in water is due to the presence of calcium or magnesium bicarbonate (that is, insoluble calcium or magnesium carbonate is chemically combined with carbonic acid to form soluble bicarbonate), or to the presence of calcium or magnesium chlorides or sulfates. All of these compounds unite very readily with soap to form an insoluble sticky "curd."

Some of the soap is destroyed in this way before it has a chance to make a lather for cleansing purposes, the amount destroyed, of course, depending on the amount of hardness present. It is therefore not economical to use water containing much of these compounds for laundry work. Another disadvantage lies in the fact that the curd so formed sticks to the clothing and is difficult to rinse away, and under the heat of the iron its discoloring effect is considerably increased.

The effect of boiling on calcium bicarbonate

Boiling the water decomposes the calcium bicarbonate into calcium carbonate with liberation of carbon dioxide, and the insoluble calcium carbonate will not react with the soap, so that the water has been thereby softened. The calcium or magnesium sulfates and chlorides, however, all require the use of sodium carbonate or some other alkali to react with them to produce calcium or magnesium carbonate and sodium sulfate or sodium chloride, none of which react with soap. Therefore, the use of some washing soda or similar compound to soften hard water containing chlorides or sulfates is essential if soap is to be saved.

Moreover, a *very slight excess* of an alkali above that amount required to remove the hardness will improve the de-

tergent properties of the soap. It is also claimed that the presence of free alkali will help to change the fats and oil, present in all soiled linen, into soaps which can be readily rinsed away; but probably it merely emulsifies them; and for this purpose, borax is superior to any of the other alkalies. In any case, a trace of the alkali has a better emulsifying action than an excess.

Another reason for using some alkali in laundry work is to prevent the formation of insoluble acid soaps which occurs occasionally, the presence of which on the fabric is indicated by the formation of spots or marks when the article is ironed. This is effected if the alkali is added with or before the soap, but is not much use for this purpose if added to the water after the soap is dissolved.

It is evident, therefore, that the use of some small amount of an alkali is useful in laundry work, but an excess of any kind, either as a softening agent or in the soap, is to be avoided owing to its action on the fibers, which has been already discussed. We have shown that caustic soda or sodium silicate should never be used. Carbonate, if not in excess and if rinsed away thoroughly, can be used with cotton or linen, but borax or ammonia (and preferably borax) is the best to use with wool or silk. Ammonia unless quite weak soon deteriorates silk. The amount of alkali (particularly of soda) commonly used by the housewife and in commercial laundry work is usually far in excess of the amount required, resulting in a discoloration and destruction of the goods. The use of a "sour", as is usual in power laundry work after excess soda has been used, will certainly neutralize the soda left in and prevent further discoloration under the action of the iron, but it does not prevent the deterioration and discoloration of the fiber which has surely taken place in the hot bath. Excess soda should, therefore, never be used at any stage. Probably never more than one ounce to about seven gallons should be used for the most soiled articles being washed in a moderately hard water; but the results will be better, though a little more time and soap may be needed, if not more than one ounce to about twelve gallons is used; and this *dissolved in the water before the soap is added*, or added to the soap jelly before pouring it into the bulk of the water.

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PRIMITIVE METHODS STILL USED IN SPAIN

AN ILLUMINATING EXAMPLE OF DEFIANCE OF THE BODY BY AN UNCONQUERABLE MIND

ROBERT LOUIS STEVENSON

The memorial by the American sculptor Augustus Saint Gaudens, in St Giles's Church, Edinburgh

BALANCE OF MIND AND BODY

How the Body must be Treated so that the Mind may Retain its Health

MENS SANA IN CORPORE SANO

OUR course hitherto has been simple. But now that we have discussed the body's needs of such things as air and water, and light and sleep and covering as to which all sane men would agree, we pass to a new department of our subject, where personal conduct is more evidently involved, and where they may differ.

We have undertaken to discuss the health of man, and hitherto we have practically ignored his mind. That has not mattered so far, but it does now, when we are approaching questions of exercise and diet, and must decide whether to serve the body as it inclines is necessarily to serve the mind; whether we are to use our minds to find what our bodies like or our bodies to serve our minds; whether physical exercise is necessary to develop our muscle because we ought to develop muscles; whether physical exercise is good or bad for brain exercise, and so on.

The first principle of all the pages that are to follow is that the soul being the all-important part of man, the body exists to serve it. It is a great conception, of which every age has need, our own not the least. No doubt the body is often a burden, and its needs a hardship, and we incline sometimes to rebel. The nervous system insists upon sleeping away something like one-third of our lives, in vegetable fashion. Many a man, not only the pleasure-lover, but especially the student resents that necessity, and tries to overcome it, in the interests of his mind and its activity. The results are often appalling, and yet we must honor the man who worked while others slept

It will therefore be a problem for the future to learn such control of the nervous system that all or many of us may be able to sleep so *deeply*—that is, so *quickly*—as to spare more time for the waking life But this is not a task for ignorance to essay upon itself; and many are the disasters wrought in the past upon the mind, in the supposed interests of the mind, because men did not comprehend how long vigils may damage the brain, which is the chief organ of the mind.

Then, again, we spend much time in dressing and undressing, and in washing. We cannot even have our useless nails attended to once and for all, but have to remember that they will not even keep clean for an hour at a time

Similarly there is the problem of the hair; and while this is serious enough for everybody, especially if we try to keep the scalp clean, most men feel impelled or required to shave the hair of the face, as keeping it young, or as keeping it clean or less likely to bear infection. But still the waste of time and inconvenience is considerable.

Add the need of eating and drinking, brushing the teeth, and so forth, and we see that the burden of the body, though largely made pleasurable, is a very heavy one. Perhaps we should realize the weight of this burden of ours if, instead of our own bodies, it were someone else's upon which we had to wait incessantly, feeding and scrubbing, and clipping and paring, and dressing and undressing it every day. One almost wishes, at times, when mental interests are absorbing, that it were possible to be rid of one's body altogether.

How physical and psychical needs go hand in hand

But the body is a servant which, however troublesome and vexatious, and even humiliating, in its coarser necessities, is yet indispensable to our welfare. This is an old servant of the family, and it pays us to treat him well, though it is disastrous to make of him a pampered menial for whom we soon come to live. His welfare is never an end in itself. That sounds reasonable enough, but it has serious consequences. Thus, as we shall see, though we must recognize the value and the duty of sensible exercise, we must view with contempt the extravagant cult of muscle, as such, which is one of the ludicrous follies of the age.

We have to look upon the body as the temple of man; we must worship the god it enshrines, but to worship the temple itself is mere idolatry. Many sensible and many profound people are nowadays inclined to protest against the modern interest in health, on the ground that it concerns itself too much with things which are only means to ends, and not worth anything in themselves. The Psalmist was right to remind us that the Lord "taketh not pleasure in the legs of a man"; and though we shall discuss the physical exercises that concern the health of the legs of a man, it will not be that the man shall boast of his legs, but that they shall carry him well where he wishes to go.

Many people — but by no means all — seem improved in mind by illness or weakness; many who are always fine become finer still. But, on the whole, we find that physical ill-health leads to mental and even to moral ill-health. Our lunatics are physically ill and weakly; and they improve, in the great majority of cases, when we can get more flesh and fat upon their bones, and improve their digestion. Certainly all people do not need the same advice in this matter; but no less certainly we now believe that the relation between health and holiness is not only etymological but also physiological.

This will not mean license, for license does not mean bodily health, and therefore does not serve mental health, but, on the other hand, except in the matter of sleep it is very far from being a defect in meeting the requirements of the body that prevents most of us from reaching our full height — and length here below — as *psychical* beings; or, in other words, from enjoying life to the utmost possible.

There is really now no room for doubt that the great majority of well-to-do people are guilty of gross excess in the matter of food. It is not merely the body, observe, that we are now thinking of, but the mind, or the body in relation to the mind. The argument is not merely that most of us simply eat more than we need, or that we carry about with us more fat than is required for the warmth or protection or reserve needs of the body, but that we eat and drink more than is good for the health of the mind, and, above all, for the longevity of the mind.

The relation between excess of diet and premature mental decay

This is a great question, which will need to be considered when we come to study the problems of old age. Meanwhile let us beware of supposing that growth, maturity, senility, and even something very like death are confined to the body alone. There is the mind to consider as well; and history is full of cases where people have prematurely lost their mental powers because of some dietetic excess. Indeed, no one yet knows what should be the application of the word "premature" in this connection. But we may make the anticipatory guess, derived from the records of great biography, that too old at forty need not — should not — apply to the mind, nor even, we may dare to believe, too old at eighty.

There is no inherent reason why the saying of Schiller should be true, that the lamp of genius burns quicker than the lamp of life. On the contrary, the mind, even here on our planet, may often all but visibly survive the body. Certainly there are octogenarians among us today whose names are known and honored not alone for what they have done, but for what they are doing.

The need for the preservation of the youth of the brain

Some of them, though possibly deaf, lame, muscularly feeble, though perhaps even "palsy shakes a few, sad, last gray hairs", are doing fine work today, displaying the great spectacle of essentially young heads on old shoulders, alike enthusiastic and experienced, which a wise hygiene promises to many more in the future.

Some may say that the difference between these few and the many lies in the quality of the mind. But it is not in the least a materialistic assertion that the difference lies in the quality of that part of the body known as the brain, the chief organ of the mind. The mind can only play on the organ it has got, so to speak. If a man has good and fine mental qualities, and takes proper care of his mental organ, those qualities will not leave him. The brains of the old men whom we have described are still relatively young brains. It cannot be pretended that any brain at eighty is what it was at thirty or forty, but many an octogenarian brain is structurally and practically younger than many an ill-used brain of half its nominal age.

The care of his nervous system the first duty of man

The brains of the wise. who practise what is here preached, have always been their owners' first care. They have not been systematically exposed to food-poisoning, drink-poisoning or drug-poisoning. Thus the legs of a man may grow lame, his skin wrinkled, the lens of his eye dim, but so long as his brain is supplied by soft arteries with pure blood, the man himself, as we wisely say, will be *all there.*

Hence the conclusion that the essential part of the body of a man, which it is his business to take care of, is his nervous system. Professor Auguste Forel, the great Swiss psychologist, has well written that: "With human beings the brain is the organ of the mind, and there is far more justification in what we know nowadays for saying 'The brain is the man' than Buffon had in his time for saying 'The style is the man.'"

The psyche manifests itself chiefly but not exclusively in the brain

It would be more accurate to say the *psyche* is the man; but as we are here discussing not philosophy but practical hygiene, the brain is the man will serve as the key to our argument.

An important note is here needed. The *psyche* lives not only in the brain, though chiefly there. "The mind is as deep as the viscera," to quote the final verdict of a great thinker. Therefore we shall not be able to despise the care even of the humblest organs if we find that their care is reflected in the state of the brain and the mind. In brief, the question which every wise man should put to himself, and which the writer on hygiene must attempt to answer, is: "How should I treat my body so as best and longest to preserve the health, the vigor, and therefore, so to speak, the happiness of my brain, which, for practical purposes, is myself?" When the question is thus framed, the essentially ethical character of hygiene, as here understood, will be evident.

We conceive the *whole duty of health* in such terms that it definitely serves morality, being health of the whole man; and we claim that, if we can establish the large dependence of the brain's health upon the body's, the care of the body becomes a religious duty, so long as it is directed towards the service not of itself, but of the mind.

The powerfulness of the reactions of the body on the mind

While some religionists, especially concerned with healing, teach that health is controlled by infinite Mind, and their followers theoretically refuse medical aid when ill, we must not forget the important truth that the body reacts on the mind, and mere consciousness of personal beauty or ugliness, physical strength or lack of it, affects the mind and even conduct as a whole. The reactions are various. The knowledge of beauty will make one woman vain, another sympathetic for the less fortunate; the knowledge of strength will make one man a bully, another gentle.

But the reactions exist; and if that be granted the body cannot be ignored. Again, it cannot be doubted that, other things being equal, the man with the most active digestion may tend to be the man with the most active mental energy; or, at any rate, the man with a high measure of physical energy which may be run into mental channels.

Again, the brain, like every tiny particle of nerve tissue, is intensely dependent upon the quality of the blood supplied to it, and thus "depending for its action on a due supply of blood, duly purified, must be affected in its efficiency by every variation in the development of this or that excreting organ." This means, in brief, that to attend to the health of the liver, the bowel, the kidneys, is undoubtedly to affect the blood-supply of the brain, and so determine its usefulness and longevity, as well as the kind of temper, in small things and great, that we may display from moment to moment. As Herbert Spencer has put it: "So, too, in active life the visceral derangements produced by overwork and anxiety are often followed by ill-temper. Even the recognized differences between irritability before and equanimity (sometimes joined with generosity) after dinner suffice to show that when flagging pulsation and impoverished blood are exchanged for vigorous pulsation and enriched blood, there results the change in the balance of the emotions which constitutes a moral change."

The brain an original endowment that may be developed but not added to

A creative hygiene, in any adequate sense of the words, is not possible for the adult. He is already long past the really constructive stage of brain-culture. So far as we can ascertain, intellectual work, diet of any kind, exercise, or anything else, will fail to add a single cell to those which his brain possesses, or seriously to modify the main lines, already laid down, of the connections between them. But if a creative hygiene is impossible, or nearly so, a recreative hygiene is not. What has been formed may at least be maintained, by means which we are about to define.

The existing number of cells in the brain cannot be increased. But we have found that there are a great many cells in the adult brain which, so far as we can judge, are doing nothing, because, though they are present and alive, they have never left their embryonic conditions.

The subject is still highly obscure. But these "neuroblastic cells", or "neuroblasts", as they are called, may very possibly be capable of response to suitable conditions, so that, instead of being inactive, they become active. This is not the same process as causing one's nerve-cells to divide and multiply, which is definitely known to be impossible. But, from the practical point of view, it comes to just the same thing. The future hygiene of adolescence and middle age may be largely concerned with the factors which persuade all one's nerve-cells to develop up to the point when they really begin to function; and it will very likely be found that the development of the brain may be continued far beyond the limits which any other part of the body can hope for. The discovery of these neuroblasts in the adult brain may give us the key to the fashion in which the mental powers of some persons appear to undergo a real increase far on into maturity or even senility of the body, and such exceptional cases may some day be made common.

A fateful warning — the hopelessness of renewing deteriorated brain tissue

But that is speculation. What is quite certain is that the maintenance of what the brain already possesses is already largely within our control, and that it is only a quite small minority who, at present, can be acquitted of neglecting this duty, the discharge of which would have been worth so much to them. We cannot hope to repair damage already done to the brain, and the facts of damage should be remembered when we are proposing to avoid it. Here, again, prevention is better than cure, because it is largely possible where cure is not. If nerve-cells, in the brain or elsewhere, have already been destroyed, they cannot be restored. Their place will be taken by tissue which *cannot think*.

How all questions of health concentrate at last on the brain

All cell-destruction is irreparable. Even a relatively humble structure like the skin is incapable of replacing a single hair-follicle, once lost. Much more is this true of the brain, whose cells are incapable of division. But while creation of the brain is difficult or impossible, and replacement of its losses impossible, its maintenance, which is the commonest of its needs, is far more possible than any but the hygienist recognizes.

And, just because the body is really one, and just because the brain is in touch with every part of it, and is nourished by blood, the composition of which is affected by every part of the body, everything is liable to matter for the health of the brain. All that we have already discussed bears upon it; so also does our future study of habits, of the use of stimulants and narcotics, of exercise of the muscles, the senses, the intellect, the emotions, as well as the question of everyday diet. Though the next part of our discussion is devoted to physical exercise, which we commonly associate with youth, and which youth needs more than any other period of life, yet we shall see that it concerns other ages also, not least that of middle age.

Need for widening the summit between the ascent and descent of the hill of life

We refer specially to the man of middle age, who suffers from no obvious, perhaps as yet no actual, disease, yet who is not quite so fit as he used to be, plays no more active games, is doubtful whether he has time nowadays for any exercise at all, is beginning to "put on flesh" — which is not flesh, but fat — has less initiative, less enthusiasm, and, in a word, is beginning to descend the hill of life. The pity is that so many of us start this descent as soon as we stop ascending. At the top of the ascent of life we should come to a long, level tableland, whereon we should spend many years — decades, indeed — before we begin, slowly, to slope away to the end. And it is pre-eminently of the *psyche* that we are thinking in this image.

Certainly there is no occasion for the state of the man whom we have just described. He must expect to lose some bodily agility at forty or less. The experience of the finest athletes, including those who have lived the wisest lives, is conclusive in showing that physical agility cannot be maintained unimpaired in the forties; but it is no less conclusive in showing how skill — which is a state of the brain, not of the muscles or joints — may be maintained almost indefinitely. The man of forty has no business to lose his agility of mind for another three decades at least. He and we are the losers in that, just when his powers have reached their height and he has accumulated much experience, he begins to fall away. Many such men are responsible for this calamity themselves, or would be if they knew the facts which it is our business to unravel. They largely sin in ignorance, and are perhaps even doing their best, with pills and potions and belauded tonics, to repair their youthful vigor. Yet all the while they may be sinning against the laws of hygiene; and in a wiser age many such men will be looked upon as the obvious glutton and inebriate are already looked upon in our own day.

Knowledge is no less essential than good intentions. The man we have described has a multitude of counsellors in whom there is anything but safety. He may embark upon violent dietetic changes which rob him of essentials of diet or produce serious dyspepsia, perhaps with marked constipation, and thus aggravate his condition. He may damage himself with drugs, and even acquire a drug habit. He may undertake absurdly unsuitable exercises, perfectly adapted for the hippopotamus, but ill-suited for man, and may thus strain his heart or his arteries in irremediable fashion. All these things are happening every day around us.

Attention to health must not be excessive, however well intentioned. It must suit the condition of the individual. It must not concentrate all his attention upon himself: such concentration may be the original cause of all the troubles which he seeks to relieve.

Bristol Brass Corporation

Man and machine — shaping nature's products to fit human needs. Here a brass sheet is sheared to size.

POWER-DRIVEN TOOLS

The Wonderful Instruments with Which Man Builds the Many Machines of Modern Industry

MACHINES WHICH SEEM ALMOST TO THINK

THE most important things in modern industry are not always the most impressive. When we see a gigantic machine pick up a car of coal and dump it into the hold of a vessel or when we see the great hand-like "claw" of a hoisting crane grab up a ton of rock and transport it to another location with accuracy and apparent ease, we stand in awe of the great display of power and cannot but admire the genius of the man who planned the monster machine. But back of every machine there must be *men* and *tools*, and many of the latter used in making the great engines and power-driven machines of industry are even more intricate and marvelous in their perfection of action than their product.

The true history of man's toilsome journey from savagery to civilization is not written in the chronicles of kings and princes but in the story of the development of his tools of production. It is measured by the distance from the stone ax to the turret lathe, from the dugout to the ocean liner, from the bow and arrow to the 16-inch gun.

It is a curious and unexplainable fact that until about one hundred and fifty years ago man had made comparatively little progress in fashioning tools to assist himself in his work. He had devised simple hand tools, such as the ax and the saw, centuries before. The discovery of iron smelting enabled him to improve the quality of these and to develop the other simple handicraft tools that are still common. But in all industry the important thing was the *skill of the worker*, the tool being only a more or less imperfect aid in his work.

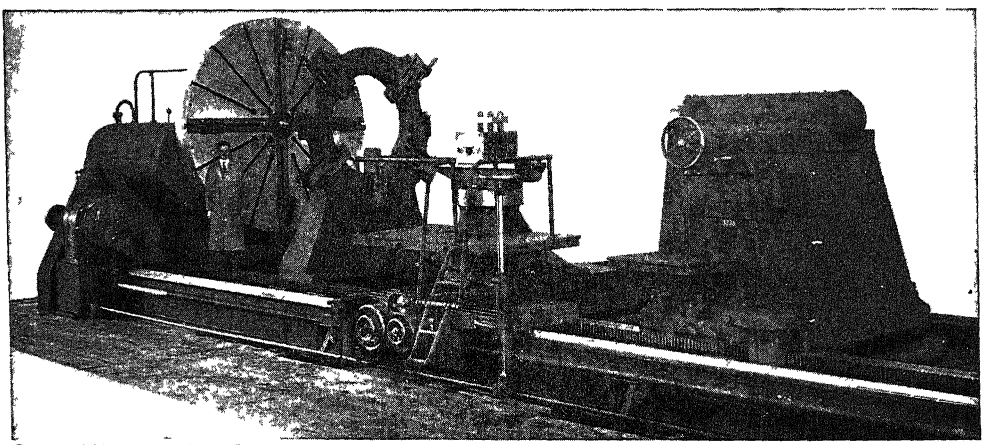
About the middle of the eighteenth century there began in England a marvelous improvement in machines for industrial purposes. It is true that machines had been constructed before that time, but they were crude indeed compared to modern implements. Machines are made for the most part of hard metals, such as iron, steel and brass, and the necessity of working these hard metals into properly shaped pieces for the myriad machines of modern industry has resulted in the development of some very interesting and wonderful tools. The name of "machine-tools" has been given to those machines which workers in metal use for shaping the parts of other machines. Back of all the marvelous machinery of modern industry are these "master tools" on which the parts of these complicated machines have been fashioned. We have given the general name of "machine shop" to the factories where these master tools are installed and where other machines are built.

In the beginning of the modern industrial era all manner of machines were built in the same shop, but as industry has grown and broadened it has been found to be more economical to build only a limited variety of machines in each shop. To-day, therefore, we find special shops devoted to building ships, steam engines, locomotives, typewriters, agricultural machinery, and so on throughout the immense range of modern machine building.

A visit to one of the great plants where machinery, ships, locomotives, or other industrial equipment is manufactured is most bewildering to the uninitiated.

Here is a little machine doing work almost miscroscopic, while not far away are gigantic tools weighing many tons and requiring great power to operate. The small one is removing very tiny particles of metal from some little machine part while its large neighbor may be shaving off the armor plates of a dreadnought or boring the inside of a 16-inch cannon for its armament.

To the casual observer these interesting machine-tools may appear to be of endless variety, but a closer examination would disclose the fact that they all belong to one of a very limited number of types or families, of which the most important as well as the oldest is that which includes all lathes, so-called.



Courtesy Niles-Bement-Pond Co

This great lathe will machine a piece 156 inches in diameter.

In working with the lathe the piece to be machined is caused to revolve and a cutting tool of hard steel shapes either the outside or the inside of the piece into circular form. The lathe is made in many models and in sizes ranging from those that may be carried easily in one hand to those weighing many tons.

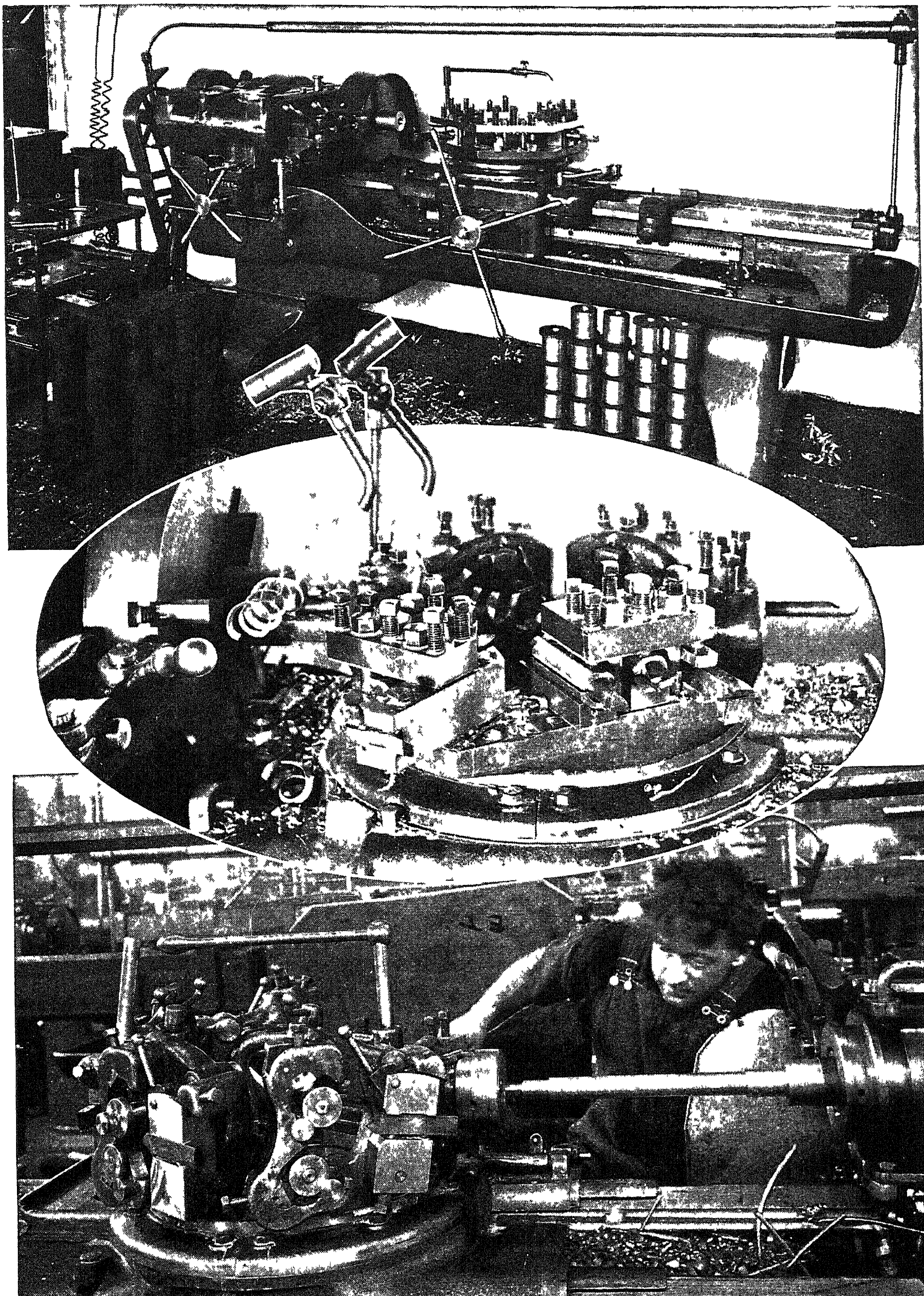
The boring mill may be considered as a modified lathe, but constant development has entitled it to a distinct place among machine-tools. In some kinds the piece to be machined revolves, as in the lathe, while in others it is clamped fast to the boring mill table and the cutting tool revolves. In both the lathe and the boring mill means are provided for moving the tool and the part that is being machined relatively to each other in an axial direction so that cylinders or other figures of revolution can be readily formed.

Another great division of machine-tools is that which includes all planing machines. In the simple planing machine the work is secured to a heavy table which moves to and fro under the cutting tool, which is made fast to a cutter head which can be traversed across the surface to be machined in either a vertical or horizontal direction, thus generating all manner of rectilinear or ruled surfaces which may be flat or of some other outline. In some of the smaller forms of the planing machine this relation is reversed, the tool moving to and fro in a fixed plane while the work is traversed under it.

The drilling machine, so-called, is a tool made especially for drilling holes. The drills used are of very hard steel and will bore a hole in iron or steel with almost as much ease as a "wood-bit" bores wood. In highly developed forms of the drill press many holes are bored simultaneously.

Another important member of the machine-tool family is the milling cutter, in which the cutting tool is circular and the periphery set with teeth not unlike a circular saw; in fact it is, in effect, a wide saw for cutting metal. The part to be machined is secured to a table or platen which can be traversed to and fro under the cutter which may be shaped to cut a narrow slot or some other of a great variety of forms. Often more than one is operated on one spindle, making a "gang" of cutters.

A TURRET LATHE AND HOW IT WORKS



Courtesy Jones & Lamson Machine Co

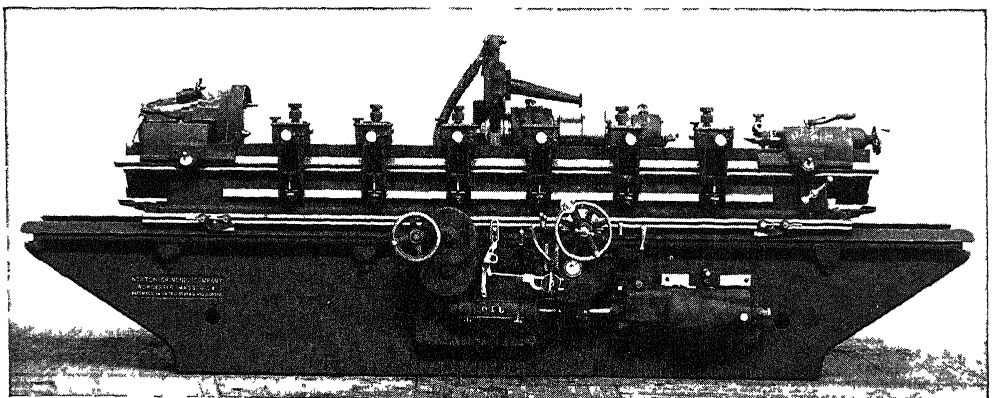
In the upper picture, near the middle, the cutting tools can be seen mounted in the turret, the capstan for operating which is in front The piece which is being machined is just at the left of the turret The middle picture shows the turret at work. The chip from the cutting tool curls up at the left The bottom picture is taken from the back of the lathe The operator is about to move the turret up to the work and take a finishing cut on the threaded end of the work which projects from the spindle of the lathe.

Machines quite simple tools worked without immediate human control

In recent years the grinding machine has become a very important member of the machine-tool group. Grinding will not take off large chips of iron or steel, but on the other hand it will remove very small particles, which the ordinary cutting tool cannot, and with such accuracy as to make possible perfect trueness of form. The great precision of modern machines rests almost wholly upon the development of modern methods of grinding.

Those enumerated constitute by far the most important types of machine-tools, though there are, of course, many others which are indispensable. Thus in the boiler-shop or shipyard one will see shearing machines which will cut thick plates of metal as easily as the tailor does cloth, or which bite pieces from great bars with ridiculous ease. In the blacksmith shop will be found power-driven hammers which shape the huge metal bars that are too thick to be tackled with the puny stroke of a hand hammer, and giant power-driven presses for bending and squeezing metals either hot or cold. Many smaller tools operated by power are also seen doing work with a rapidity and ease that make man's own physical labor look little and ineffective. And then, if one wanders into another part of the same establishment, hundreds, often thousands, of small machines stand marshalled in rows, cutting all conceivable shapes, round and flat; making screws, gears and the innumerable requirements of the engineer. Many of these little machines seem instinct with life, since they require little or no attendance when in operation.

But always without exception the machine is more than the man behind it; its movements alone cut and shape the forms of metal intrusted to its charge, and the men are attendants — hands, operators, machine-minders only, whose duty lies in feeding the imperious demands of the inanimate but powerful and accurate machines with materials.



Courtesy Norton Grinding Co

A MODERN GRINDING MACHINE

This tool will grind a piece 18 inches in diameter and 8 feet long which is held on the conical "centers" at each end and rotated, while the grindstone — seen in the middle — travels to and fro removing the metal.

Where early machines got the name of "Iron Man"

It was not always so. Nearly all these marvelous machine-tools which fill the shops have been developed since the beginning of the nineteenth century. Their main idea is nothing more than that of taking a carpenter's chisel, plane or saw, or an engineer's file or drill from the control of the hand, and placing it under a rigidly constrained mechanical movement.

It is curious to recall how some of the early machine-tools had the name "Iron Man" applied to them. The beginnings of this idea go far back into prehistoric ages, when neolithic man attached a stone axehead to a handle, or a pointed implement to a bowstring.

Yet it is only about a hundred and fifty years since the tools used in the turning-lathe were first taken from the workman's puny hands, and fastened on a mechanical carriage, which resulted in the "slide-rest", a fitting which is present in some form or other in nearly all machine-tools. This epoch-making invention began to revolutionize the methods of cutting metal. It gave a means of controlling the tool, and of enabling it to far excel any workman in power and in accuracy of cutting.

Why not, then, make the tool much bigger, so as to cut the whole width or length of a surface at a stroke, instead of slowly nibbling at it with a narrow point of a tool? The reason lies in the great difference between cutting iron or steel, and soft materials like wood. Every one knows how easily a chisel or a knife will cut wood. Yet if we try the same tool on iron it will do no more than inflict a very slight scratch, and damage itself in doing that. By very much lessening the keenness of its edge, and

Courtesy Niles-Bement-Pond Co.

CHIPS FROM LOCOMOTIVE DRIVING WHEEL TIRES

Forty three hundred pounds of such steel chips have been removed in ten hours by a Pond New Model Car-Wheel Lathe

It is remarkable, in the vast arrays of machines which are at work in the machine-shops, how utterly insignificant a thing the actual element — the cutting tool — appears. It is generally a small bar of steel, which a child could pick up with one hand, yet the whole structure of the complex machine has been designed and built at enormous cost with the object of enabling this little cutter to do its duty upon the surface of the iron and steel castings and forgings intrusted to it.

putting it in a machine, the tool becomes capable of taking shavings from the hardest iron, but at a much slower, a painfully slower, rate than the soft wood can be shaved off.

And so the wider we make its edge and the more we try to cut, at once the greater is the resistance, until at a certain stage it is quite impossible to force the tool to its work without breaking it, and damaging the piece of work, and the machine into the bargain.

This is why such an insignificant looking tool does the work of cutting over a large surface, or turning a shaft or gun, or boring a cylinder. Though the actual tool is always small by comparison with the machine, there is a way of increasing the output of machines by multiplying the number of tools held in one machine. Some kinds of turning-lathes have four, eight, or more tools cutting simultaneously at different parts of the piece of work being machined. And the tools have not always only a single cutting portion on them, as, for instance, the milling cutters, which have a number of teeth each taking a shaving off the metal as the cutter revolves, like a paddle-wheel churning into water. In drilling holes, an immense amount of time is saved by increasing the number of drills, as many as thirty or forty drills descending simultaneously and boring their way into the metal in the same period of time that one drill would do one hole. Many machines will drill holes at both ends of a long cylinder or pipe simultaneously.

All this cutting demands a large amount of power to hold the tools to the work and to force them along, or to force the work along, as the case may be, otherwise the machine would stop for sheer want of driving force, or something would break.

The power behind some machines is enormous, from the point of view of a person unfamiliar with the difficulty of cutting metal. The big lathes require as much as 60 to 100 horse-power to cut the chips off, and this continuously while the lathe is turning. The terrific pressure produced in the operation of turning may be imagined from the fact that for every square inch of steel removed there is a pressure of a hundred tons on the tool, trying to push it away. The heat generated often makes the end of the tool red-hot, and the shavings cannot be touched as they curl crackling off, to the accompaniment of smoke. Many tons of steel are thus removed on some lathes in the course of a working day. A new kind of steel for cutting tools, only introduced within this century, has already helped greatly to increase the output of machines, because it will cut three or four times as fast as the kind of steel previously used — and does not require resharpening nearly so quickly.

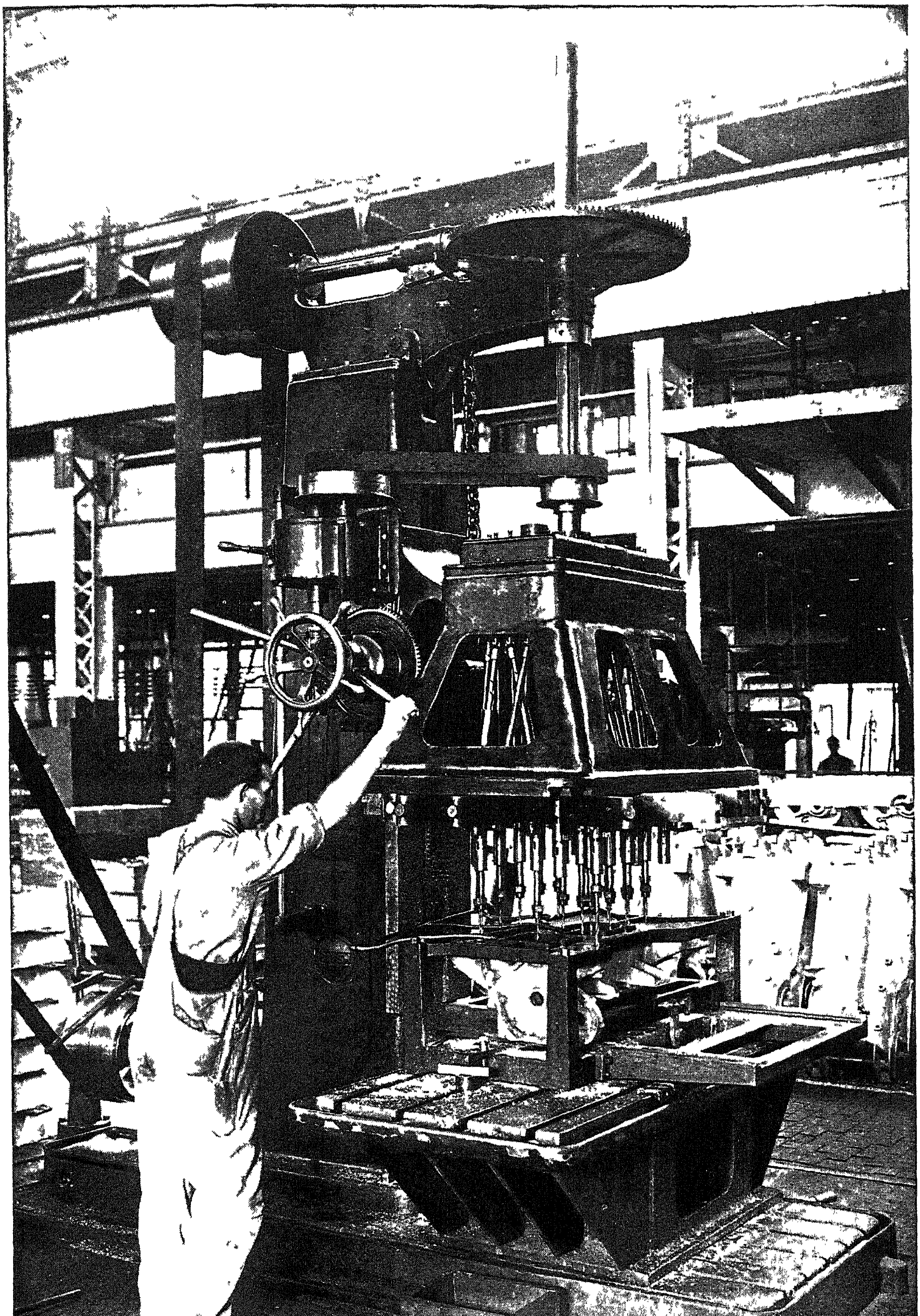
Courtesy Niles-Bement-Pond Co

TYPICAL CUTTING TOOL FOR HEAVY WORK

These tools are made of steel containing an alloy such as tungsten or vanadium to make them very hard yet capable of holding a cutting edge

A tool does not necessarily bear the slightest resemblance to the form of the work which it cuts into shape. It may be only a straight piece of bar with the end ground into a curved or a straight shape, and the rest is done by the controlling

THIRTEEN HOLES AT A SINGLE STROKE

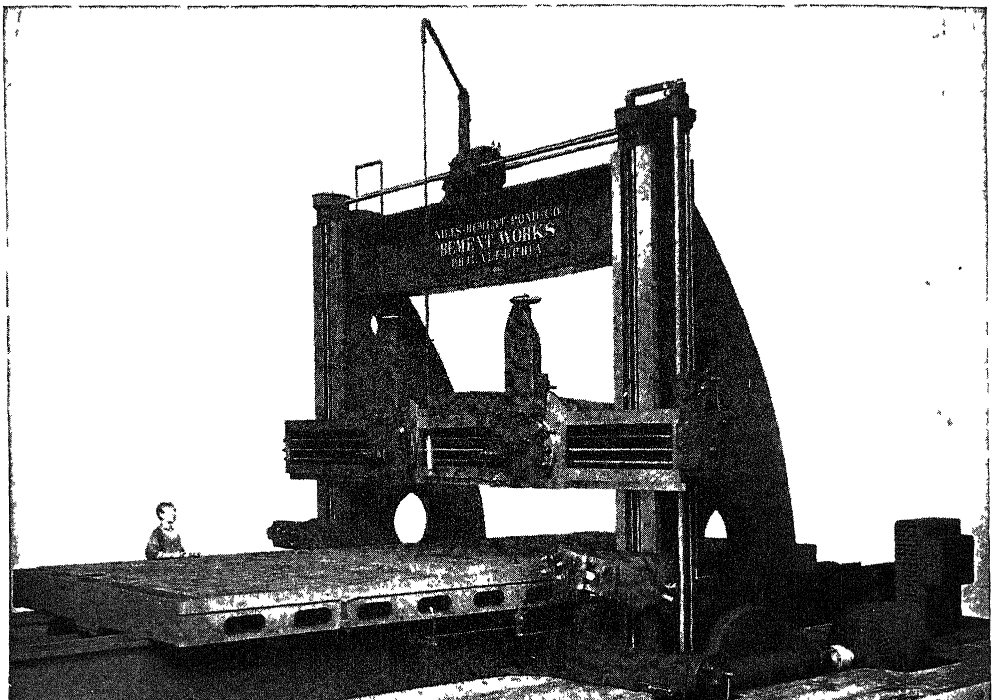


Courtesy Baush Machine Tool Co

A MULTIPLE-SPINDLE DRILLING MACHINE

Boring thirteen holes of different sizes simultaneously in a base for an automobile engine.

influence of the machine, which moves and adjusts the various parts in such a manner that the desired outline is given to the metal. On the other hand, there may be some recognizable feature about the tools, which gives a clue to their purpose: and when one operation has to be repeated day after day on hundreds or thousands of pieces identical in shape, the tool may "fit" the work very closely, simply because it pays to make it specially for that one purpose.



Courtesy Niles-Bement-Pond Co

A BIG PLANING MACHINE

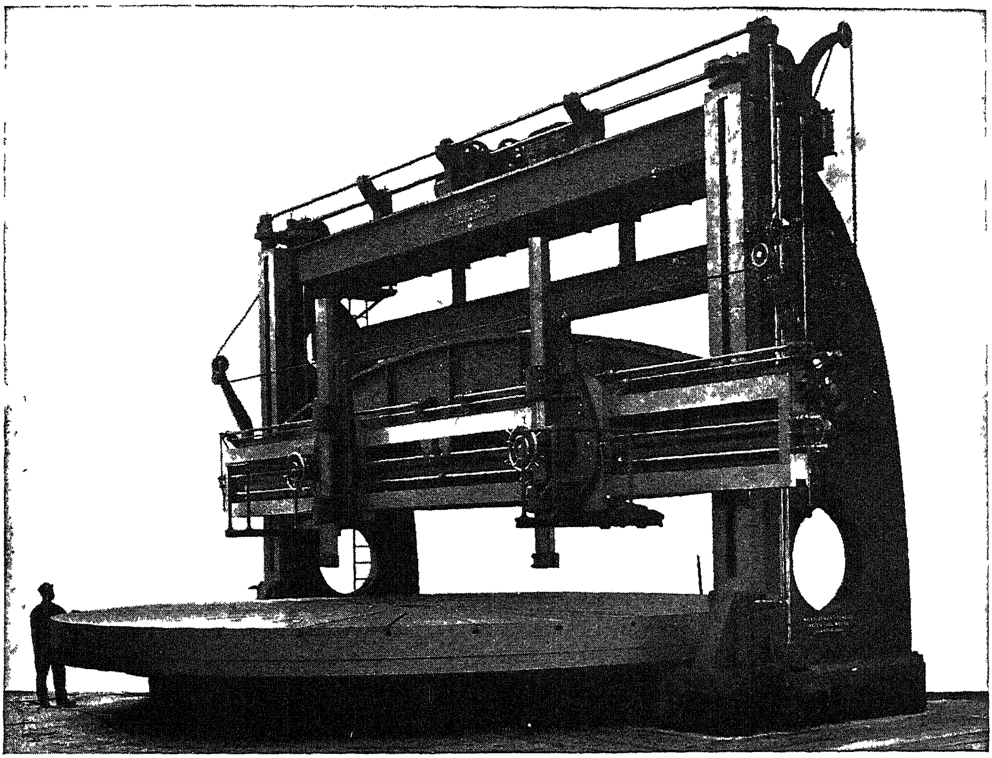
This machine will finish a piece $6\frac{1}{2}$ by 10 feet square and 15 feet long on three sides simultaneously The electric motor on the right moves the great table which carries the part to and fro, and the heads which carry the cutting tools are to be seen above and on both sides of it

So wonderfully is the science of cutting metals carried out in workshops that produce hundreds of similar mechanisms, as sewing machines, typewriters, cash registers, or guns, and so accurately do the machine-tools operate, that it is possible to take any part from a heap and fit it to its place in the mechanism without filing, or dealing with it by hand in any way. Inspect the parts of an automobile, an engine of any kind on land or sea, a crane, a watch, a clock; examine the spindles, the gears, the screws, the valves, the joints, and the rest, and try to conceive by what means all these parts were so beautifully fashioned. Go a stage further, and remember that when you see one complete piece of mechanism there are thousands more exactly like it, and that, from any single one in all those thousands, any individual piece can be taken and fitted into any one of any of the other similar mechanisms without adjustment or worry. All this is accomplished by the marvelous machines which perform their tireless tasks, and produce such beautiful results without any meddlesome correction on the part of their attendants.

This means that each piece must be of a certain definite size, no larger and no smaller. But as it is impossible for anyone in the world to produce *perfectly* accurate things, engineers must perforce be content with what they call a "limit" size; that is, a shaft or screw or a hole will be within certain sizes, neither larger nor smaller, though a slight inaccuracy may nevertheless be present.

But this which we call an "inaccuracy" is only measurable in thousandths of an inch. Tissue-paper is about one thousandth of an inch thick, yet this is coarse by comparison with the limits of size which metal parts can be and are cut to. A two-thousandth or a five-thousandth part of an inch is quite commonly worked to and a remarkable thing is that these extremely fine limits are regularly obtained notwithstanding that the tools are wearing away,

Such remarkably fine work as this may be better understood if we mention that a plug and a ring ground so finely to fit each other will, if the plug is inserted in the ring, stick fast unless they are kept in movement, simply by the molecular attraction of the metals The temperature of the human hand will also make such a fit easy or tight As the wheels wear, a compensating arrangement has to be used to make up for that



Courtesy Niles-Bement-Pond Co.

A KING AMONG BORING MILLS

This great tool will finish the inside or the outside of circular pieces, like large flywheels, 36 feet in diameter.

and that there is elasticity in the machines themselves which is likely to interfere with their accurate working. The finest results possible are not obtained by the regular cutting tools of steel, but by the revolving grinding-wheels of emery, corundum and carborundum. This again is a very odd fact, because these wheels wear much more rapidly than the steel tools. And yet it is only by using one of these that it is possible to grind to one fifty-thousandth part of an inch,

Another thing in favor of grinding is that the hardest materials which cannot be cut with steel tools can be ground with ease. Nothing is too hard to be ground. This explains why we so often see the term "hardened and ground" in relation to some of the parts of an automobile; the steel is hardened to enable it to resist wear, and it is ground because that is the only way in which it can be finished properly.

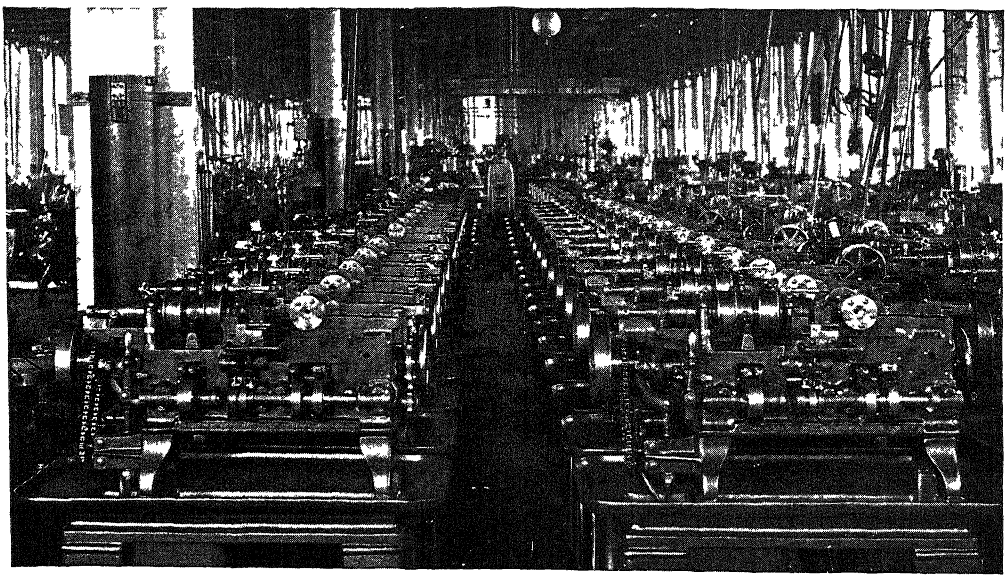
The most remarkable aspects of some machine-tools, as viewed by the stranger

unfamiliar with the sight, is the self-acting, or automatic, character of their movements. By these in some cases the tool is moved to a certain predetermined distance, and then runs back quickly to its starting-place without the intervention of the man who stands by. Often these reciprocating movements are performed by a table on which the piece of work is fastened. Or, again, the tool cuts deeper and deeper at each successive reversal, and when the correct depth is reached it will not work any longer, but ceases its movements.

Or if a gear is having its teeth shaped, the spaces between the cogs or teeth are all made exactly alike, being divided round by the machine itself as the gear rotates in the brief intervals of cutting. Or if a drill is making a hole, the machine sends the drill forward by a precise and measured amount at each turn, and we see it steadily descending, often at a rate of an inch in a few seconds. When these movements are once adjusted or "set", they go on operating without intervention.

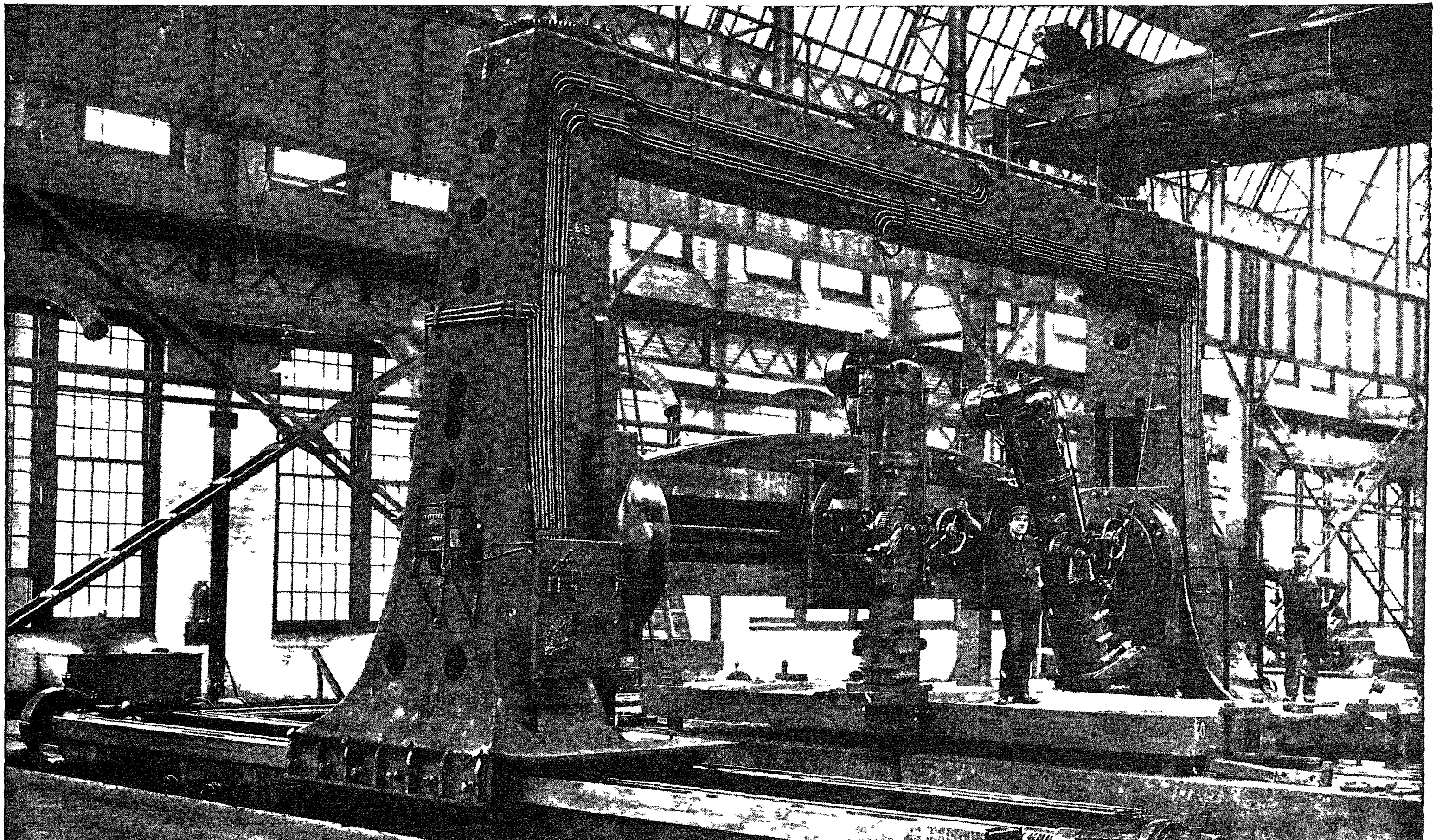
So completely automatic are some machines that the attendant may leave them for a long while, and he is thus able to look after a whole row, conscious that, excepting by accident, nothing can go wrong, and that the machines will of themselves stop should they have used up all the material. The ringing of a bell frequently gives warning of this.

The most wonderful and complete examples of automatic working, which never fail to interest visitors, are the automatic lathes or screw-making machines, which make screws and parts from lengths of plain bar. In these the tools are multiplied in number, but each one is of a different kind, and they are set around the edges of a rotating holder, called a "turret", which automatically brings the required one round in turn, causes it to cut the work in a certain fashion, and then makes it retreat, and swings round another tool. As many as eighteen or twenty distinct kinds of tools can be thus manipulated, and the only reason for stopping the machine is the need of sharpening when the tool edges become dull. So long as the machine is supplied with one length of bar after another it will continue to produce the screws or other parts. By an ingenious application of fingers and chutes it is now easy to feed these machines with small separate parts which have been cast or forged nearly to shape, and are thus fed, gripped, cut to shape, and again released to make room on the machine for the succeeding piece.



MAKING MACHINES THAT THINK FOR THEMSELVES
The assembly room of the Brown & Sharpe Co at Providence, R I, showing a number of automatic lathes about completed.

A 12-FOOT PIT PLANING MACHINE IN AN ARMOR PLATE SHOP



Courtesy Niles Bement-Pond Co

This giant among machine tools, in the armor plate shop of the Midvale Steel Co, weighs over 500 000 pounds and is one of the largest ever built. It will finish the four edges and one face of an armor plate 24 feet long, 12 feet wide and 12 inches thick at one setting. The cross rails and heads swivel to any angle. Each head has an independent motor drive. The machine is driven by electric motors through pneumatically operated clutches and all the various traverses are by means of electric motors controlled from switchboards mounted on the columns

There are many "fool-proof" devices incorporated in machines, which prevent stupid blunders by careless or absent-minded attendants. The various handles and levers by which the machine is started and stopped, and the movements adjusted and varied in speed, are often interlocked, so that the operator cannot throw in conflicting mechanisms and produce grave injury to a valuable machine. So many machines are now compulsorily guarded in parts which contain revolving gears and wheels that the attendant cannot see the internals of the machine; all that he is aware of is the handles outside, and these are numbered, so that by referring to a chart he can see which ones to move in a certain position to get certain results.

The unwearied machine that never changes its endlessly repeated work

In machines which cost hundreds or thousands of dollars it is necessary to take precautions against accidents, which perhaps involve a heavy repair bill, and many interesting provisions are made to allow for overstrain through putting too much work on the machine. As the strength of a chain is in its weakest link, so the strength of machines may be governed by an element so proportioned that it will break or shear off if the safe limit of force is exceeded. When this happens, a pin or bar snaps in the driving mechanism, and acts like a safety-valve in preventing further overworking. But for this, shafts would become twisted, gears would have their teeth ripped out, parts of the framing would be cracked, and human life would be endangered.

Injury to workmen is prevented not only by guarding the flying wheels and shafts, but also in more complicated ways. Sometimes a stamping or punching machine is so constructed that it cannot be started unless the attendant places both his hands on levers. He has then no more hands left to get in the way of the descending punch, to be mangled. Or a hinged lever may be arranged so that it sweeps across the space beneath the descending tool, and compels the removal of the worker's hand just in time.

The long rows of machines that make the same things year after year

A great difference between the old and modern machine-shops is that in the former the machines were intended for a whole range of miscellaneous operations, while in modern shops, which specialize in some product there are hundreds of special machines doing nothing but one kind of machining day after day, week after week, year after year, on articles often never varying even in size. There is so much of the same kind of cutting or grinding that it pays a firm to have a special machine for doing that little bit of an operation; in fact, they would lose largely if they did not use such a machine, and the product would be unsatisfactory. Some machines make one kind of gear all the time, another cuts off bars of steel in readiness for other machines, others never do anything but turn railway axles, others nothing but railway wheels or tires. And not one machine only, but long rows of them, are seen in the great railroad shops, doing the same thing today that they have been doing day after day continuously for many years.

In the automobile industry this specialization is very marked indeed, and there are special machines for such an apparently trivial function as cutting oil grooves, others for rounding the teeth of the gears which slide into each other in the gear-boxes, and many others too numerous to mention. In fact, every industry, from implements of peace to weapons of war, invokes the help of a vast array of special machines which are designed and built for that industry alone.

Whither is it all tending? Machines should lighten the load of human drudgery, but as yet they appear to have increased it. The lot of a mere machine-minder is not an enviable one. His faculties are not exercised as they would be in the practice of a craft. He has become an automaton — nearly as mechanical as the machine he tends. But on the other hand, machinery has given employment to vast numbers who would otherwise have been hard put to it to earn their living.

METALLURGICAL DEVELOPMENTS

It is of more than ordinary significance that within a very few years the science of Metallurgy has shifted from the study of the simple metals almost wholly to that of their alloys and attempted alloys. The metallurgist of today recognizes the possibility of producing different properties in one and the same metal by the introduction of what had before been adjudged an impurity to be carefully gotten rid of. In another direction, the physical qualities for so long considered typical of the metal in question have been completely changed by heat-treating. Research in metallurgy is being carried out on a large scale, and methods and means of testing both the metals and their alloys have been developed from various angles; and the recent advances in chemical technology have been found of the largest importance in the metal worker's task. In the development of alloys, particularly of the ferrous group, where several alloying elements are used simultaneously, a number of new results have been obtained. In the face of competition from new structural materials, such as glass, paper and plastics, the metallurgical engineer has had to call upon the inventor to aid him in selecting a metal for a certain desired purpose, or in constructing a new metallic element in the form of an alloy. The task is not alone to attain suitability in the new metal by empirical trial, but its performance must be closely watched, for developing deficiencies may have to be remedied, even to the extent of making a change in its composition. Beyond this chemical work are the intimate variations from the normal produced by the modern methods of fabrication—rolling, drawing, extrusion, casting under great pressures, plating in the electrolytic baths, etc. In these conditions, metallurgy has quite suddenly found itself in a new era, with no boundaries.

Aluminum

A new process for the electrolytic refining of aluminum develops a purity of 99.995 per cent for the product. The electrolyte contains substantial quantities of barium chloride—a typical bath consisting of aluminum fluoride 23 parts, sodium fluoride 17 parts, and barium chloride 60 parts. The chief advantage of this mixture is that it can be maintained in a suitably fluid condition at a temperature of 1,400° Fahrenheit. This low working temperature permits also a low construction cost for the furnace, the use of crude magnesia brick being sufficient. The anode alloy contains an average of 33 per cent copper. The cells operate at an intensity of 40 amperes per square decimeter and at nine volts—a current of 10,000 amperes being employed. The aluminum thus produced is extremely resistant to a number of the acids and alkalies, and also to corrosion by sea water; and possesses a far superior electrical conductivity to that of aluminum refined by usual methods. The lightweight structural alloys of aluminum are heat treated (becoming thus the duralumin of airplane manufacture), and this alloy is most commonly used for high strength structural purposes—the heat treatment followed by quenching, causing a precipitation of certain constituents with a notable increase in strength, hardness, and general workability, without a lowering of elongation values. By this treatment strengths comparable to those of alloy steels are available. On the other hand, the modulus of elasticity is only one-third that of steel. Plates of this form of aluminum up to 120 inches in width may be rolled,

and extruded shapes up to 12 inches in diameter are available. Welding and flame cutting are not possible with these heat treated alloys, steel rivets being employed in making joints. Instances of the structural use of these aluminum alloys are to be found in the Gallipolis dam in the Ohio River; in the floor of a bridge at Bridgeport, Conn., and in the floor of the Smithfield Street bridge at Pittsburgh, Pa.

Copper and nickel alloys

The alloys of copper and nickel (with 20 to 30 per cent nickel) are more in demand than for some time, as they rate high in corrosion resistance and are very strong. These alloys are especially suitable for marine condenser tubing and salt-water lines. Besides their resistance to corrosion in salt water, they prevent fouling by marine growths. In the condenser-tube field the copper-nickel alloys have a very large use, though simple copper metal is being increasingly used for all water supplies, oil supply lines, vapor lines, etc. Some of the newer alloys contain both tin and aluminum, constituting an aluminum brass. Antimony is being added to many brasses to prevent loss of the zinc constituent. An alloy of great promise is nickel-aluminum bronze, with high percentages of both nickel and aluminum.

Alloys of gold

The physical and chemical properties of gold make it highly useful for many purposes, especially in the manufacture of chemicals where a great degree of purity is required and a comparatively large quantity of this metal is in such employment. Gold has a high melting point (1,940° Fahrenheit) and does not oxidize even at a high temperature. It is completely resistant to all mineral acids except aqua regia—in which it is readily soluble. Since the pure gold is very soft, it is usually alloyed with other metals in small proportion, platinum being often preferred, since the resulting alloys have an increased resistance to chemical corrosion. It is known that the prehistoric South American natives alloyed gold with platinum by the process of mixing grains of platinum with gold dust and subjecting the mixture to the heat of a charcoal fire raised to a high degree by the use of a blowpipe. While the platinum did not melt in this flame, the gold did and acted as a binder for the platinum. The gold in the melted state slowly permeated the platinum while hot, and after cooling the alloy was hammered into homogeneous plates. The rayon industry is using a gold-platinum alloy as the most satisfactory material so far developed for spinnerets. Gold-palladium alloys have also been found quite successful.

Iron and steel

The manufacture of semi-molten iron of exceptional purity, at a low temperature, has been in recent years brought to a status of commercial development. The new process draws the metal direct from the ore, melting the hot product electrically. In the ingot, this iron is 99.84 per cent pure, and may be used in the fabrication of high grade metal sheets for cold pressing, as required in the motor industry. This new iron is in immense demand for the making of stainless, high speed, copper-silicon, molybdenum, and other high-class steels.

Intensive study of cast-iron (pig iron) has revealed that grains of graphite abound in certain cast-irons and form the starting point of ruptures. Between these grains are found pure iron and iron carbide; and when this iron is heated to 1,300° Fahrenheit, the iron carbide tends to decompose and oxygen penetrates into the graphite grains and connects them. In the layer directly subjected to the fire, alpha iron is changed to gamma iron, and thus produces variation in the metal causing it to scale and break. For cast-iron to be used at temperatures below 1,300°, the addition of silicon, manganese, or chromium confers corrosion resistance. Where temperatures are to be above 1,650°, nickel has sometimes been used, but this metal lowers the transformation point of the alpha iron. Silicon, aluminum, and chromium raise

this transformation point, and their action is therefore deemed favorable. However, there still remains the necessity of finding the element which can appreciably improve the mechanical properties of cast-iron designed to be used at a high temperature.

Many of the metal requirements of the aeronautic and automotive engineers are now being sought for usual structural purposes. In the more recent buildings and bridges stress concentrations, fatigue and creep phenomena have been given unaccustomed prominence. Several moduli of elasticity are available in the market: as 29,000,000 for low alloy steel; 25,000,000, for high alloy and stainless steels; 10,300,000 for aluminum alloys and 6,500,000 for magnesium alloys. Conditions of corrosion and surface irregularities become highly important when thin members, permitted by high-strength materials are used, as these features accentuate the possibility of failure through fatigue. The thinner these members are, the more difficult to calculate them mathematically. Factors of safety may readily be reduced by refinement in design, or in line with desired economy, but the "ultimate" factor of safety must be kept high enough to overcome such weakening influences. More and more are the resources of metallurgy being depended upon for metal conditioning, especially as to low alloy structural steels, and as to stainless or chromium steels. Development of alloying combinations is a complex operation, each alloy often acting differently in the presence of another—sometimes a desirable effect; in other cases, detrimental.

The new steels, in comparison with mild carbon steel, are characterized by a lower carbon content and a higher yield point, but with very little reduction in ductility, and a somewhat higher ratio of yield to ultimate strength and a high corrosion resistance. Manganese, nickel, chromium and silicon are efficient strengtheners, while copper, phosphorus, molybdenum and vanadium are useful auxiliary elements. Copper, nickel, phosphorus and chromium enhance corrosion resistance. The new stainless steels are different from that in the arches of the Eads St. Louis bridge (in 1880), in that they contain nickel to improve their physical properties, and molybdenum and silicon have been added to increase surface stability. Made in the electric furnace, and requiring other special manufacturing operations, stainless steels are highly expensive, costing about 30 cents per pound—as against one cent for mild carbon steel. Consequently, they are rare in structural work. Examples of their use are in the expansion joints of the TVA dams; the separation sheets between the old and the new portions of the Aswan dam in Egypt (where 2,500 tons have been employed); for reinforcing rods for concrete at the Hawk's Nest (W. Va.) power plant; for the wire in the auxiliary counterweight cables in the Cape Cod lift bridge; for the tie rods (40 feet long and four inches in diameter) across the dome of St. Paul's Cathedral in London; and for the trash racks at the Holtwood power plant on the Susquehanna River. The immense amount of special steels in the well-known bridges and buildings are not of the new low alloy steels; most of this material is structural silicon steel, though nickel steel and heat-treated steels are frequently found in eyebars. The great cantilever span in the San Francisco-Oakland bridge is of nickel steel. Manganese steel is represented only in the Bayonne (N. J.) arch bridge. In the Cleveland (Ohio) Terminal tower, about one-fourth of its 17,000 tons is of silicon steel.

In response to the demand for heavy equipment for chemical plants, a practical method has been developed for bonding a thin nickel sheet to a heavier steel sheet. This product can be rolled or made into sheets of all dimensions. It is as malleable as steel and can readily be joined by welding. A pure nickel welding rod is used. The nickel layer is usually 10 per cent of the total thickness—sufficient to stand any usual cor-

rosion, and all necessary bending, hammering, and polishing. A new alloy, containing 35 per cent of chromium and 7 per cent of aluminum has proved an excellent combination for service at temperatures up to 2,300° Fahrenheit. Steels containing up to 3.5 per cent of chromium are now known as mild alloy steels, and have largely displaced simple carbon steels because of their greater strength and resistance to atmospheric corrosion.

A list of the elements that are used for modifying the properties of straight chromium steels include: nickel, silicon, manganese, molybdenum, copper, tungsten, columbium, titanium, nitrogen, aluminum, sulphur, solenium, zirconium and vanadium.

Alloys of lead

The most recent developments as to lead are in its alloys. One of the larger lead producers has introduced a new type of chemical lead, containing from 0.04 to 0.08 per cent of copper and 0.02 per cent of bismuth. This alloy can be used for many purposes as satisfactorily as the chemically pure lead; and, in addition, it possesses several advantages in its mechanical properties. One of the spectacular recent developments is tellurium-lead (ordinary lead plus about 0.05 per cent of tellurium). It exhibits resistance to corrosion by hot concentrated sulphuric acid and has a higher endurance (fatigue) limit than pure lead—and thus longer life and better service under drastic conditions. An important property is its capacity for hardening under hammering, which is not true of lead or its usual alloys. Tellurium-lead is now in large demand in the form of sheets, pipe, and various shapes in various industries—notably in storage batteries of the Planté type and for cable sheathing. The battery plates are made by a swaging process. Other new alloys of lead are: (1) with 0.25 per cent cadmium and 0.50 per cent antimony; (2) 0.25 per cent cadmium and 1.50 per cent tin; and (3) 0.25 per cent cadmium with 0.40 per cent tin. Sheets and pipe made of these alloys are stiffer than those of ordinary lead, and superior in tensile strength. Moreover, they are easily handled and readily welded and soldered. For bearing lead, the new alloy is formed by the addition of calcium, which has the effect of raising its initial melting point, so that it will hold safely at a "smoking" temperature—where ordinary lead would melt. For telephone-cable sheathing, the lead is alloyed with 0.03 to 0.04 per cent of calcium, this alloy being of good strength and high endurance, resisting corrosion as well as the antimonial lead usually employed. A lead alloy containing 0.1 per cent of calcium (after heat treatment) replaces satisfactorily the 10 per cent antimonial-lead grids in storage batteries. Alloys of 7 per cent tin and 93 per cent lead have been found an excellent substitute for tank linings, heating coils, and anodes where chromium plating has failed. The addition of 1 per cent of silver to lead forms an insoluble anode, very desirable in producing commercial zinc of high purity, reducing the former lead content to about one-tenth of that in the usual electrolytically refined zinc. Antimonial lead ("hard lead") is widely used in the construction industries—for roofing, gutters, leaders, etc. It is also employed by rayon manufacturers for pump bodies, valves, and other equipment. The chemical industries use hard lead for tank lining and coils. The quantity of antimony in the lead commonly runs from 6 per cent for rolled sheets and roofing to 28 per cent for the nozzles in rayon plants. However, for all these uses the new tellurium-lead, described above, has proved a satisfactory substitute. A new process for treating alloys of lead and antimony (at least 20 per cent of antimony) consists in forming a molten bath of the alloy, simultaneously agitating and lowering the temperature thereof, and treating it with a drying agent to yield a dross containing 65 to 80 per cent of antimony. The original temperature of the bath (750° to 800° Fahrenheit) is lowered at the rate of 15° to 25° per hour to about

525° at which temperature the drying agent (petroleum coke, or rosin, or both) is added. The dross is removed by shoveling and the temperature of the bath is lowered to 490°, when a crust forms, containing the excess of antimony over the eutectic ratios of lead and antimony (13 per cent antimony). The eutectic metal is removed and a fresh charge is mixed with the crust for similar treatment.

Production of metallic magnesium

Announcement of a new process for the production of metallic magnesium was made in October 1936. Attempts to obtain the metal from natural magnesium compounds by reduction with carbon have signally failed, owing to the complete reversibility of the reducing reaction. At ordinary pressures, equilibrium is on the metal-forming side only above 2,000° centigrade (3,632° Fahrenheit), at which temperature the metal is in the vapor phase—yielding, when condensed, a mixture of metallic dust, oxide in considerable quantity, and soot. The magnesium metal on the market is practically all produced by the electrolysis of anhydrous magnesium chloride, using a flux of molten salts to carry the electrolyte. In the new (Austrian) process, the metal is obtained by an operation in two stages: first, magnesium oxide is obtained by calcining magnesite or dolomite and is reduced by carbon in an electric furnace at a temperature of about 2,000° centigrade (3,632° Fahrenheit), which is well above the boiling point of magnesium metal. The reduced magnesium, leaving the furnace in vapor form along with the carbon gases, is then filtered to remove the accompanying dust, and cooled rapidly to 200° centigrade (392° Fahrenheit). In the second stage, this cooled product (which is a mixture of magnesium metal, oxide dust and soot) is conducted to the hot zone of an electric furnace, and heated to 800° to 1,000° centrigrade (1,472° to 1,832° Fahrenheit) in a partial vacuum in the presence of hydrogen or methane. Here the metallic magnesium is vaporized, and being brought into contact with a cooling surface, its temperature is lowered to the liquefying, but not to the solidifying point, and the liquefied metal in the form of drops falls into a bath of a hydrocarbon oil of high boiling point. This oil favors the coalescence of the drops into granules about one-sixtieth of an inch in diameter and at the same time separates any dust, so that the metal is isolated at a purity of about 99.96 per cent. Aluminum may be used as the reducing agent instead of carbon, thereby eliminating the formation of gases, so that only magnesium vapor escapes from the furnace. This new process is preferred because of the high purity of the resulting metal.

A high nickel alloy, Monel metal

A most satisfactory substitute for nickel for many purposes is Monel metal, which is probably the best known of the high nickel alloys. It consists of about 67 per cent nickel and 30 per cent copper, with a small amount of iron added. This alloy has been produced and sold at a much lower price than any other high nickel alloy. For a great many uses, too, Monel metal has superior properties, and often gives more satisfaction at a lower cost than would be possible with a purer composition. Besides all this, it has recently been improved by the addition of about 3.5 per cent of aluminum. The new alloy is known to the trade as K Monel metal. It exhibits an increase in mechanical properties after heat-treatment, either with or without cold rolling. Cold drawn K Monel metal in the form of rods shows a breaking strength of 165,000 pounds per square inch. It is particularly suitable for castings, where hardness and strength are required, and with silicon as the alloying element, is exceptionally useful in rolled shapes and forgings.

Use of palladium as alloy

As one of the "precious" metals, and belonging to the Platinum group, palladium is used as an alloy in combinations of other metals in this group. It is easily soluble in aqua regia, and to a

less extent in hot sulphuric acid, and slightly in nitric acid; but resists all other acids. Palladium melts at the temperature of 2,825° Fahrenheit, and is usually marketed in the form of sponge or meal, at an average purity of 99.94 per cent. It is not melted until required for fabrication, when it is usually melted on a lime hearth, and cast in graphite molds—though recently the use of graphite in such cases is criticised. Palladium has a high affinity for hydrogen, and in a condition of fusion readily dissolves oxygen. It should not be overheated as it is then volatile. A very small content of sulphur renders it brittle. When used with the other platinum metals as an alloy, the resulting metal is annealed at about 1,800° F.

Platinum

The caustic alkalies, alkaline earths, the cyanides of the alkalines, and a few other chemicals corrode platinum in high temperatures, but it is resistant to mineral acids excepting only hot concentrated sulphuric acid which attacks it mildly. Practically any shape may be fabricated with it, and repairs are easily made. Important quantities of platinum are used as the catalyst in the new synthetic organic chemistry, now developing rapidly, with increasing demand. In the rayon industry it is largely used for spinnerets, where it is necessary that metal employed shall withstand abrasion. Another important use is in the glass industry, in which its alloy with rhodium has banished the former difficulty arising from attack by the molten glass upon the pouring dies. Platinum and platinum-rhodium alloys have proved satisfactory in resistance furnaces, where temperatures of 2,400° upward are encountered. In some of the electro-chemical processes anodes of platinum-iridium have been found indispensable. Russia still supplies the largest part of the world's platinum, about 125,000 ounces in 1935. In the same year, Colombia supplied 48,000 ounces; Canada, 40,000 ounces; and South Africa, 19,000 ounces.

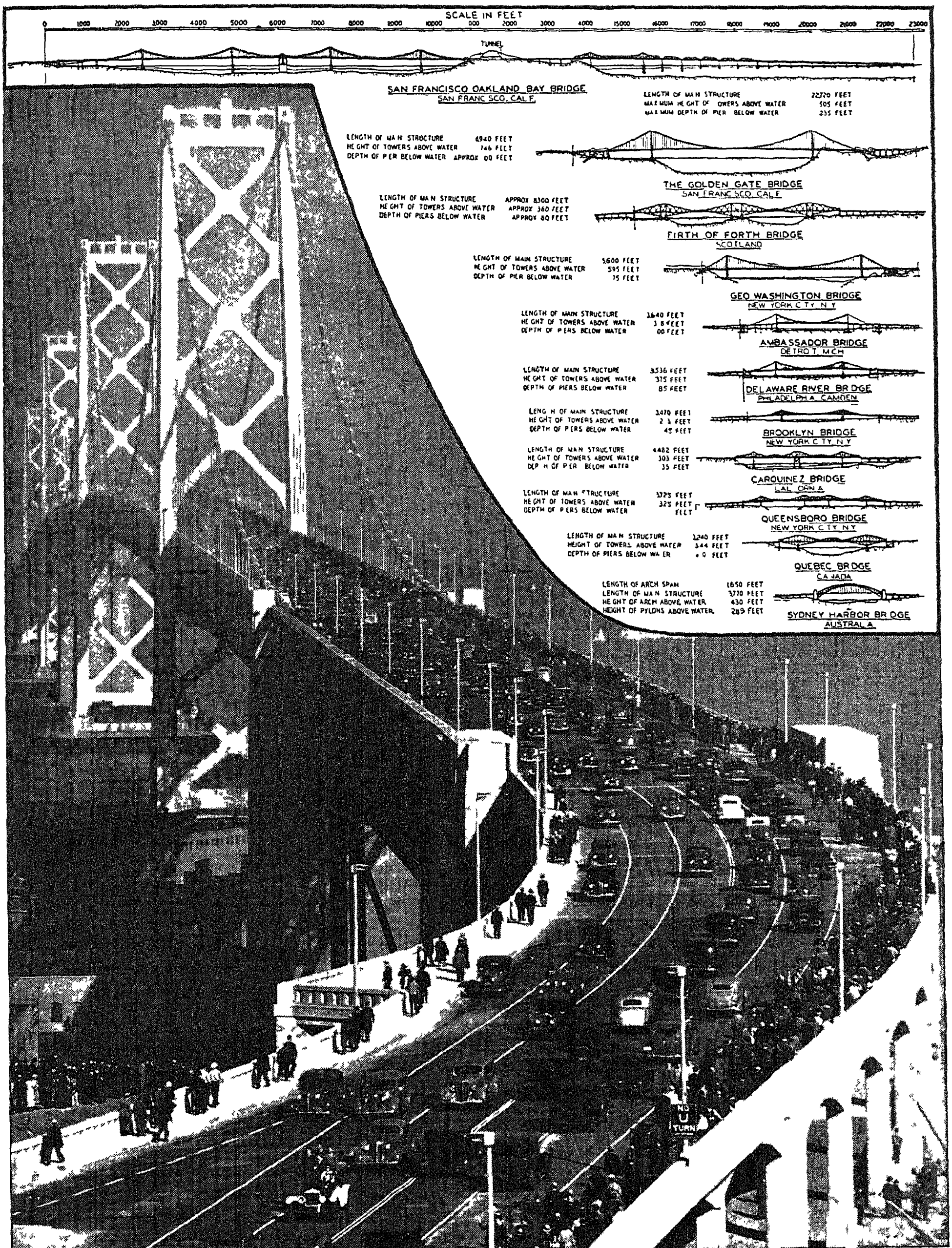
Silver

Pure silver is most often employed for equipment purposes, though sterling silver (7.5 per cent copper) or coin silver (10 per cent copper) is found equally good in some cases. The alloys are less resistant to corrosion than silver 999 fine, though their strength is greater. When annealed, silver has a tensile strength of 20,000 to 25,000 pounds per square inch. When hardened by rolling or hammering the strength of silver runs from 40,000 to 45,000 pounds per square inch, and in this form it is less electropositive than annealed silver. For general use, electroplating is the simplest and least costly method of producing a silver surface. For assurance against porosity, it is customary practice to roll out a composite plate of silver soldered (with silver solder) to a base metal. From this, silver-lined vessels are formed, usually by pressure. Silver vessels are in demand by the food industries in preference to those of other metals because of resistance to corrosion, freedom from discoloration, lack of metallic taste, and the ease with which a silver surface can be kept free of bacteria. A new use for silver is seen in its use solid or as a lining in the vacuum pans in tanneries. The ease with which silver can be welded to other metals, and in repairing worn silver vessels, adds to its usefulness.

Tin alloys

The extraordinary increase in the demand for tin, and its corresponding increase in cost, may find an explanation of its widely extended use in the new system of bronze plating upon steel preparatory to the finishing plating with chromium. The superior brilliancy and lasting qualities of chromium needed only the foundation of bronze to increase its use to a phenomenal degree. In order to avoid the imperfections of tin plating on sheet iron (as used in the canning industry) a new process employs the addition of an electroplated surface upon the ordinary hot-dip tin coating. This electroplate of tin is ex-

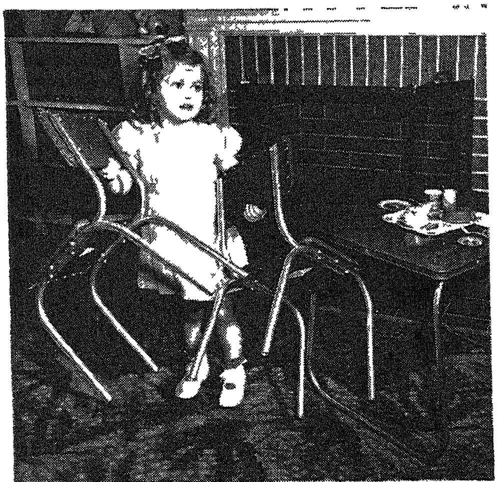
ONE OF THE GREATEST OF ALL BRIDGES



Wide World Photos, Inc.

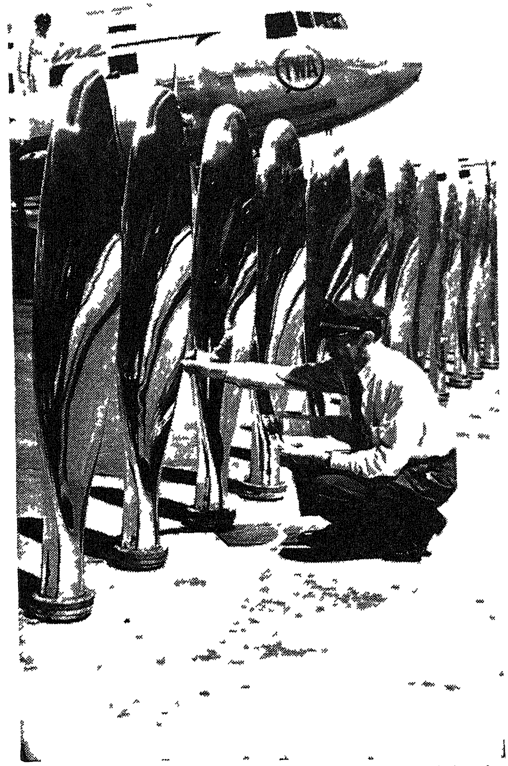
This magnificent bridge spans San Francisco Bay by way of Yerba Buena Island, taking the place of the hordes of ferryboats that used to shuttle thousands of passengers back and forth between San Francisco and Oakland and Berkeley across the Bay. It is really a series of bridges. Above we see the two great suspension bridges, each with a main span of 2,310 feet, connecting San Francisco with Yerba Buena Island. Through the island itself there runs a great tunnel. The East Bay part consists of a 1,400-foot cantilever span, 5 large and 14 smaller trunk spans. The diagrams at the top show some other great bridges by way of comparison.

MODERN USES OF LIGHTWEIGHT METALS



Both photos, Dow Chemical Co.

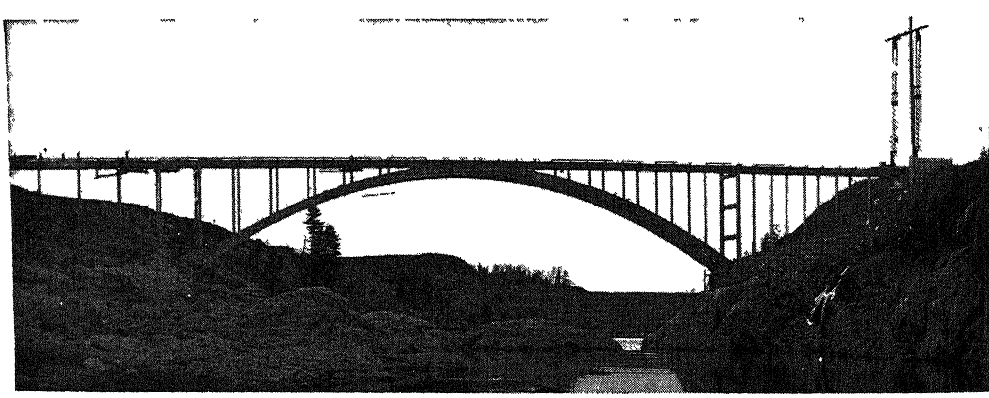
The magnesium-tubing framework of these chairs is so light that the little girl lifts them easily.



Aluminum Co. of America

Duralumin, an alloy of aluminum and magnesium, is a favorite material for airplane propellers.

This fly-rod case (left) is made of magnesium; it is very light and strong, and is rustproof, too.



Aluminum Corp. of Canada

The world's first all-aluminum highway bridge, shown here, spans the Saguenay River at Arvida, Quebec.

tremely thin and the added cost very small. For bearing metal, to stand the higher speed of modern machinery, the heavier loads, and the longer service demanded, the usual tinbase Babbitt metal has been largely strengthened by the addition of 1 per cent of cadmium. Large quantities of tin have recently been consumed in the manufacture of pewter, in response to the revival of interest in its historic use for table ware. The newest pewter is an alloy of 95 per cent tin and 5 per cent antimony—which is quite superior to the old combination of 92 per cent tin, 2 per cent copper and 6 per cent antimony. Another modern pewter is compounded of 95 per cent tin and 5 per cent silver.

Silver up to 3.5 per cent has been found to improve greatly the creep resistance of tin. Bismuth-tin alloys are more resistant to flow than is pure tin at stresses above 300 pounds per square inch. Alloying with antimony to the extent of 8.5 per cent enables tin to withstand a stress three times greater than pure tin.

Zinc alloys

Some of the newer industries which employ chemical processes necessarily conducted in conditions of a high degree of humidity, make use of heavy zinc coatings on iron or steel equipment. However, the mechanical weakness of pure zinc developed a demand for some alloy of zinc which, while suiting the purpose, should have a greater strength; and this has been obtained by the addition to 98 per cent of zinc of small amounts of cadmium, copper and magnesium. The superiority of this alloy has been attested by its wide use in roofing. In quite the opposite direction, zinc-base die casting alloys which have been subject to failure through the intercrystalline corrosion due to lead and tin impurities in commercial zinc, have been discarded, and the difficulties entirely overcome by the use of high-purity zinc (99.97 per cent). Enormous numbers of the new type die castings are in constant use. A new form of zinc-coated steel wire escapes the defects of that in former use by the device of giving the wire (after a cleansing from rustiness) an electrolytic coating of high-purity zinc, upon which the outer coating of commercial zinc is laid. Thin zinc finishes are being produced which are resistant to finger stains and to tarnishing by salty air.

Welding alloys

Probably there is no other industry in which welding plays such an important part as in the construction of containers for use in the manufacture of chemicals. Alloys are in almost all cases needed to resist the action of the constituents necessarily used. Riveting is generally out of the question, and by utilizing the process of butt welding, a perfectly clean surface is obtained both inside and out. Metals which can be welded with complete assurance of success include: stainless steel, copper, bronze, duralumin, elektron, aluminum and its wide range of alloys. In cases of corrosions the usual method of repair is to cut out the defective portion and weld in new material of the same metal. Alloys have been specially altered in proportions to permit welding. Titanium is especially valuable in replacing worn parts. Aluminum is quite difficult, because in most cases the aluminum is an alloy to begin with, and the proportions are unknown.

Lithium

The lightest solid matter ever seen or produced by man has been made at the Franklin Institute's Bartol Research Foundation Laboratories, at Swarthmore, Pa. It is a form of lithium—which is the lightest of the known metals—being the lighter of two isotopes of this metal. It has the atomic weight of 6: that is, less than twice as heavy, atom for atom, as the gas helium—used to inflate the airships of the U. S. Government. Only a tiny speck of this form of lithium has been obtained, and this was gotten by ionizing particles of the ordinary lithium (a mixture of the two isotopes

of lithium, having the atomic weight of 6.41) and shooting them into a magnetic field—which acts like a lens, concentrating the ion beam into tiny deposits.

Lithium is a white metal, which tarnishes in the air more slowly than the other alkali metals. It is a little harder than sodium but softer than lead or indium. It can be extended, rolled into sheets, pressed into wire, and welded. It can be handled at room temperatures as readily as calcium or barium. In an inert atmosphere, such as paraffin vapor, lithium can be handled up to about 200° C. This permits easy melting and pouring. It is the lightest of all metals—about five-eighths the density of potassium and less than one-third that of beryllium and magnesium.

There are no commercial uses for lithium metal alone, although when added to copper, it removes oxygen and improves the surface properties without appreciably reducing the electrical conductivity. It is reported that the addition of lithium in the refining of nickel and iron has a beneficial effect.

Other metallurgical developments

Massive bodies having a density greater than that of lead, especially for use as a shield against penetrating radiation, are made by heating a mixture of fine tungsten powder and the fine powder of another metal (which may be copper or nickel) to a temperature not to exceed 1,500° centigrade (2,732° Fahrenheit). A binder, such as a solution of wax in benzene, may be used, such a binder being removed in the course of the heating process. The usual compounds are a mixture of tungsten with 5 per cent of copper; or with 5 per cent of nickel.

A revolutionary improvement in the method of electroplating other metals with chromium has recently been announced. It consists of using a bath made up of organic chemicals which are not disclosed, and which operate to carry the chromium evenly into all the depressions in the metal being plated. Heretofore, only the higher spots were adequately plated, the lower receiving so scanty a coating that the operation was useless. A makeshift apparatus composed of a tangle of electric wires was utilized at undue expense to lay an even plating. The new process clears away every difficulty.

In a new method of making tellurium-lead alloys, especially for the sheathing metal of electric cables, the tellurium in the proportion of from 0.1 to 38 per cent is introduced into the molten lead, and the mixture heated further to the point where the lead telluride formed dissolves in the lead. The product is then cooled suddenly, and is thereafter heated with a further quantity of lead at a temperature not much above the melting point of lead.

A new type of zinc-coated steel wire has been produced by an electrolytic process, as distinct from the usual process of dipping the wire into molten zinc. The zinc deposited in the new procedure is remarkably pure; and with a previous cleansing of the steel wire from all oxide in a bath of fused sodium hydroxide, the quality obtained has created a far wider field not only for wire so treated, but also for the new plating process as superior wherever a zinc coating is desirable.

An improved bath for the heat-treatment of light alloys containing magnesium, at temperatures exceeding 275° centigrade (527° Fahrenheit), consists of fused anhydrous sodium bichromate, or fused anhydrous potassium bichromate, or a mixture of the two. For example, a magnesium alloy containing 8.5 per cent of aluminum and 0.3 per cent of manganese is heated in a bath made up of three parts fused anhydrous sodium bichromate and one part of fused anhydrous potassium bichromate at a temperature of 420° centigrade (788° Fahrenheit), quenched, and then heated for two hours in an annealing furnace at a temperature of 180° centigrade (356° Fahrenheit).

ROMANCE IN THE RIVERS

Mysterious Habits of the Fresh-Water Fish Which Serve Man as Daily Food

SALMON, TROUT, STURGEON, PIKE AND EELS

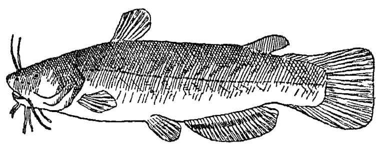
THE naturalist is not driven to sea in quest of mysteries in fish-life. Every river, pond and brook holds its secrets. Watch the goggle-eye solemnly approach a snail-infested water plant, stop, roll its eyes and then reach forth and pluck the prey with all the ease and unconcern of any browsing animal. Observe the heavy-bodied catfish as it moves slowly about over the bottom testing everywhere with its whisker-like barbels until it suddenly stands on end and pushes its mouth over some bit of refuse, — scavenger that he is. Look for the sucker resting upon the mud, drawing in the silt and straining out its organic content, disposing of the waste as two muddy streams from beneath its gill covers. See the slender-bodied pike resting motionless near the surface. A slight tremor passes over his agile frame. Seemingly without muscular effort he shoots forward and a smaller one of the tribe disappears. Well might the "smaller fry" imagine it were written above his powerful jaws: "All ye who enter here leave hope behind", for one hundred per cent of the pike's food consists of smaller fishes. Surely the naturalist need go no more sea-roaming for problems of the greatest interest will come to him, leaping, gliding, racing through the clear waters — problems as challenging as any pertaining to the life of the ocean. There is not a fish that swims our streams about which the last word has been written.

Each fish is fashioned in form and color to the life which it leads. The goggle-eye is deep-bodied, slow-moving and blotched with figures which simulate the shadows and colors of its surroundings. The catfish and sucker are as somber as the bottom over which they feed. The pike is slender and powerful to cleave the water easily in its dart for prey. All these and others in their leisure moments rise, descend, turn and stand upon end with an ease and grace found nowhere else in the animal world — not even among the birds with their wonderful aerial manœuvers.

The locomotion of fisnes is called swimming — a term wholly inadequate to describe this function. Slight but powerful lateral vibrations of the tail propel them. The fins along the side of the body serve as the adjustors of balance and the gas-filled swim-bladder within the body renders the fish bulk for bulk the same weight as the water which it displaces. Hence they may rise, descend or maintain a given level, all without muscular effort.

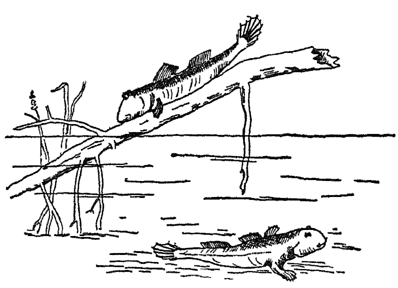
Strange as it may seem some fishes have learned to walk. The disappointing feature about them is that none of them are found in our own brooks and rivers. The mudskippers of tropical climates hop about upon the mud using their arm fins, which become thick and muscular like legs. The body supported upon them has an unmistakable frog-like appearance. The fishes become so adept in the use of these modified fins that they can climb up and along the mangrove roots to a distance of several feet above the water The batfishes have grown so skilful in walking that they have lost the art of free swimming entirely. A few fishes have even acquired something of the art of flying. Among these the arm fins are greatly enlarged so that they may maintain themselves for brief periods in the air.

If walking and flying be considered as not quite the proper thing in piscatorial conduct, then breathing air should be looked upon as still more of an aberrant practice. Fishes are provided with gills in the neck region. Here oxygen is taken from the air, dissolved in water and transferred to the blood. But certain species



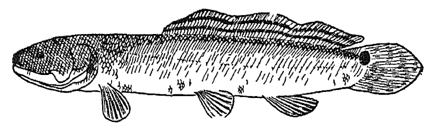
COMMON CATFISH
With its whisker-like barbels.

are too impatient, apparently, to wait for air to become dissolved in water from which it is taken through the gills. Such come to the surface and take in the air directly. The swim-bladder in these species serves as a lung. The bowfin, common in the eastern and middle United States, is notorious for its habit of breathing air directly. In lakes where it is abundant one may see them by the dozens breaking through the surface film of water, emitting a bubble of air and taking in a fresh supply. Such species, even though extreme in fish fashions, enjoy advantages denied others of their tribe. They can live for long periods out of water and survive in stagnant pools where others perish.



SOBIES
Hopping over the mud and climbing mangrove roots

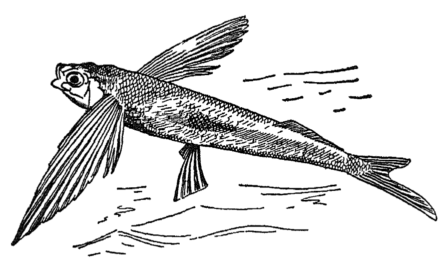
Although the observer of fishes may characterize them as marvelous rather than mysterious the latter term is surely applicable in a measure to the salmon. None other has received so much attention as the salmon and its tribe, yet these have succeeded in puzzling naturalist after naturalist, and more than one good man is remembered by the errors concerning it to which he stood committed at the end of a life of investigation. Even today, carefully as the life story of the salmon has been worked out, we do not know the whole; there are points which still need clearing up. We are more fortunate at last with that long-standing mystery, the



THE BOWFIN
Which can breathe air directly.

eel, although we have had to go to sea to find the key to the riddle But our inland waters have their other secrets, and no man need regard the subject as exhausted He may, if he will, still find work in the matter of classification of the salmon tribe, in regard to which the experts even yet are not all of the same way of thinking. For present purposes, however, the life story of some of this famous family will be of greater interest than an excursion into the domain of classification and origin.

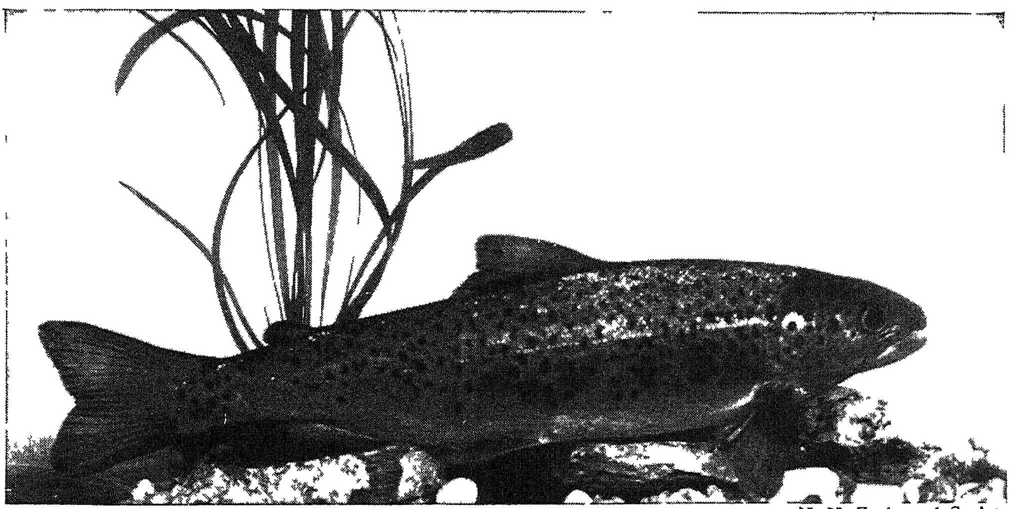
The salmon, we say, is a sea-fish which resorts to fresh water for the breeding season. For the moment we leave it at that, with a reservation — salmon ascend rivers not at breeding time. The spawning



A FLYING FISH
In an ae onautic stunt

season varies greatly with the species and locality. The Atlantic salmon performs its spawning late in October or early in November. Along the Pacific Slope salmon may be found running during every month in the year. As the time draws near the fish begin to troop in from the sea.

They make the transition from the salt water to fresh without any preliminary, though the former is absolutely fatal to their ova. There is a limit to the powers of the salmon as a leaper, so that streams with falls and obstructions too precipitous in character lack salmon. As everyone who has seen a salmon ladder knows, the fish can ascend considerable heights when thus assisted. Under natural conditions rocky heights which afford successive leaps can be negotiated, but a leap of six feet seems to be the limit of the salmon's aërial performances. Once they quit the sea the salmon appear to desire only the source of the river. They make their way upwards and onwards until they reach clear, shallow water running over a good gravelly bed, which in the case of some Pacific salmon may be 2000 miles from the sea. Here the female, attended by her lord and his rivals, makes what may be termed a rough-and-ready kind of nest. It is really a trough in the gravel, hollowed out by the action of her body. Here she deposits her eggs, not all at one time, but day after day. Each batch is fertilized by the male, and each, after fertilization, is, bar accident, covered with gravel. The number of ova depends upon the size and condition of the salmon, but about a thousand eggs for every pound weight of the fish is the universally accepted calculation.



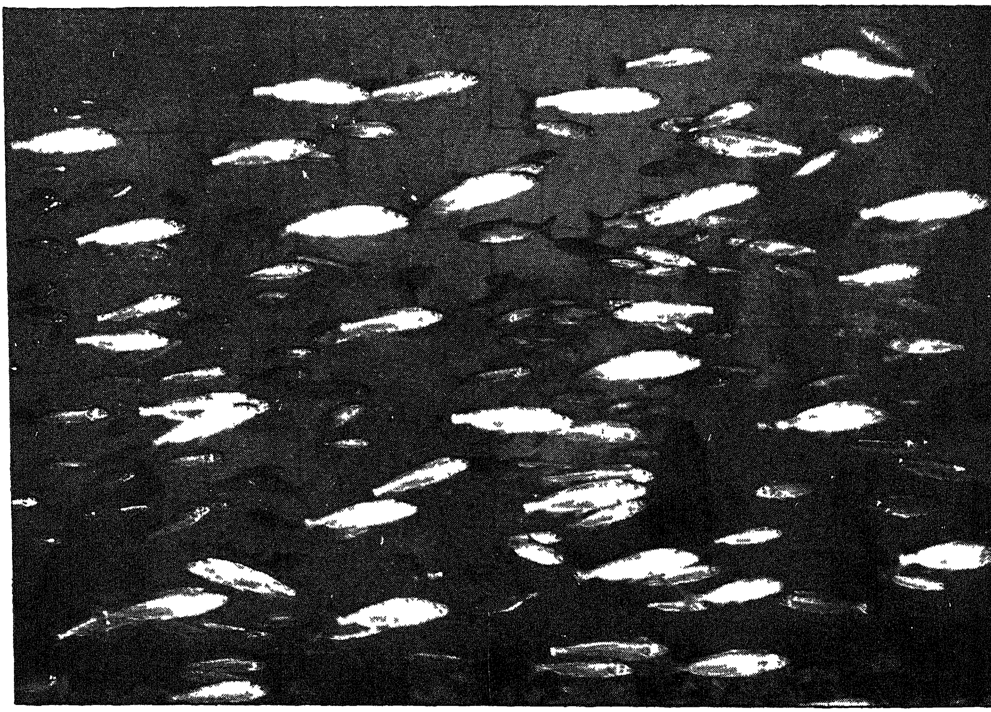
N. Y Zoological Society

A SEBAGO, OR LANDLOCKED SALMON. THIS FISH SPENDS ALL ITS DAYS IN FRESH WATER

When the eggs have been laid and fertilized, the kelts — such being the name given to salmon which have spawned — turn about and retreat to the sea. Among the Pacific salmon as soon as the eggs are deposited and fertilized the adults die, a state of affairs paralleled by some other animals and one difficult to explain. The salmon of the Atlantic variety which turn again to the sea are hardly recognizable as salmon. When they quit the sea for the river they are the picture of beauty. But as they ascend they lose their silvery hue, and a dull coppery red takes its place. The body becomes distended and slimy, and the male develops an extraordinary hooked beak to the lower jaw. A not very ancient belief was that this development was to serve for digging the trench for the eggs, and also as a weapon of offense and defense. But the female, as we have seen, makes the trench, and she, except when advanced in years, does not show this abnormality. The beak is certainly not a weapon of offense. It is cartilaginous in composition, and really prevents the salmon from opening its jaws to any appreciable extent. In this sense the beak may possibly be regarded as a kind of defensive weapon. The salmon as it runs up the river becomes so fierce when in opposition to other males that, in the restricted area in which the ova are actually de-

posited, battle with unhampered natural weapons would end most seriously for the whole family. As two queen bees, finding themselves in a position to inflict mutually fatal blows, cease their combat in order that the hive shall not be left queenless, so, perhaps, male salmon are fashioned to fight with blank cartridges, so to speak. Fatal conflicts do occur, as it is, where the larger fish are challenged by smaller, but not to anything like the extent which would inevitably be the case were all free, in the comparatively narrow limits of the spawning grounds, to wage war as they are in the wide and open sea.

The spawning season may keep the salmon four or five months from the sea. Now, in that time they do not feed! Instantly the thought comes to mind — how is it, if they do not take food in the rivers, that the angler catches them there by means of rod and line? The reason is, apparently, that the garish fly of the angler arouses the curiosity rather than the appetite of the salmon. Or it may be that the lure represents a possible luxury which may stimulate a momentary craving. Everyone who has kept fish in a pond or lake is aware that fish which are well fed and have food available exhibit curiosity; that they will critically examine and "mouth" a leaf, a blossom or other object which arouses their interest. Possibly the case is the same with salmon in the river. Be that as it may, the best opinion is that salmon, when ascending or descending from the spawning grounds, do *not* feed, and that the stories of their devouring the young of their own kind which accompany them down-stream are based upon inaccurate observation. A salmon caught in the sea may contain five or six herrings — more than a man could eat at a meal. But the river salmon — that is, the fish traveling to or from the spawning grounds — is practically never known to contain food.



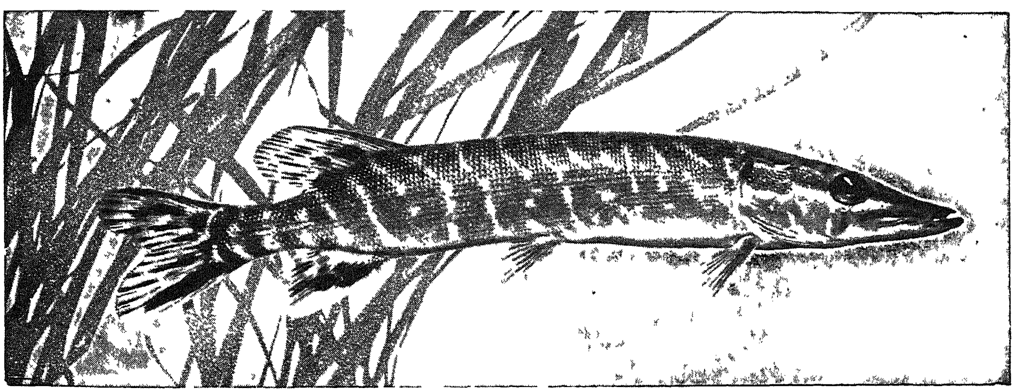
THE QUINNAT SALMON OF BRITISH COLUMBIA THAT SUPPLY THE CANNING INDUSTRY

It is common knowledge that many fish abstain from food at spawning time, but the long fast of the salmon is exceptional. The salmon fasts during a long period of extreme physical stress. The ova of the female develop and mature in that time, and the male attains its highest

pitch of physical activity. Nor is the mystery wholly ended here. It is not at spawning time alone that the salmon enters the river. In certain rivers they run at various times throughout the entire summer Why they should thus leave the sea in which their livelihood lies no man has been able to explain

That matter of development in the sea is an interesting one. Increase of weight varies, of course, with the individual fish, and with the food supply to which it finds its way. W. L. Calderwood, Inspector of Salmon Fisheries for Scotland, has at various times published interesting tables on the subject. Perhaps the most remarkable example of rapid growth is that of a smolt (a salmon in its second year), which, liberated when weighing only an ounce, turned the scale at $3\frac{1}{2}$ pounds when recaptured fourteen months later, an increase of 5600 per cent for the period Scarcely less striking, however, is the evidence from a Ness salmon which, weighing 8 pounds, and measuring 35 inches when taken out and marked, was found, six months later, to have increased its weight to 23 pounds and its length to 38 inches. Even that is eclipsed, however, by a sea-trout marked and put into the water at Coquet, in Northumberland. When taken out of the water at Aberdeen forty-nine days later, it was found to have doubled its weight, but without any addition to its length.

We must return, however, to the ova which the adult salmon have deposited at the river-head. These are exposed to many dangers from predaceous fish and birds. Frost will not hurt them any more than it hurts the bud upon a hardy tree, but the ice formed over shallow water may, upon breaking up, carry away masses of soil in which the ova are laid Cold retards hatching, so that there may be a difference of four months between the appearance of the infant salmon from two batches of eggs deposited in the same week. Thus in warm waters the eggs may hatch in as few as thirty days, while in extreme cold the period of incubation may extend over 270 days. The larva emerges from the egg with a sac attached, containing the residue of the yolk of the egg, and this constitutes its food supply for the first few days, or even weeks, of its life With the absorption of this its form assumes that of the adult salmon a little more than an inch in length and it is known as a "parr". The minute insect life of its native stream suffices to keep the young going for the first year, it may even be the first two years, of its career; but then the sea begins to call, and, like migrating birds, the little fish set out for the place whence their parents came. They have now entered upon the "smolt" stage, and are still quite insignificant in size and weight. It is a striking fact, however, not without parallel, of course, in natural history, that even while thus physically immature, the young male salmon may be capable of rendering the eggs of the female fertile. But seaward now is the aim of the teeming myriads of smolts. They are not so many as those that hatched. Birds and fish, and perhaps an otter or two, have been



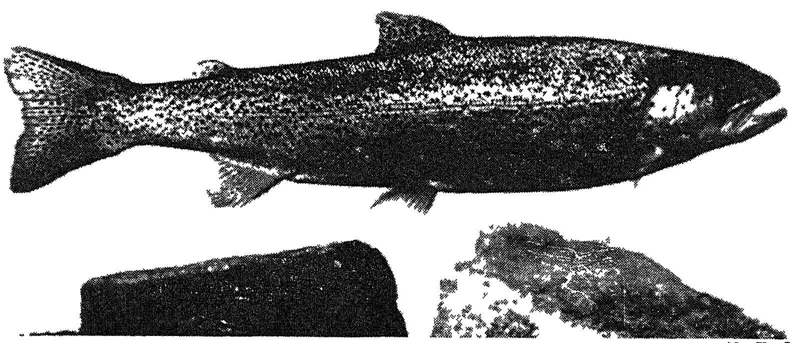
THE VORACIOUS PIKE

busily at work, and those that survive are probably the most elusive as well as most fortunate. In the sea the smolts find abundance of food — shrimps, prawns and the fry of herrings and other fish. The young salmon may stay one or two years in the sea feeding and rioting amid scenes of plenty. Then they journey to the tide waters of the sea or near the mouths of their native rivers, or they may proceed up these rivers and mingle with the adult salmon. They are now grilse, and as such, unless they feel the urge to spawn, they return to sea If, however, the instinct to reproduce summons them from the deep, then it is as kelts that they are known in their ascension to the upper waters of their native rivers and streams. The cycle of stages has now been completed — parr, smolt, grilse and kelt — and there remain only alternations between sea and river, with increase of bulk in the individual and increase of kind through reproduction. The salmon are very exhausted after spawning, and the males never return to the sea. But the females may recover and return to the sea for a time, after which they again return to breed; and this process may be repeated several times.

As a rule, salmon return to the rivers in which they were hatched, but the retaking of marked fish shows that the rule has many exceptions. Possibly the supposed predilection for native waters has really a geographical explanation. The outgoing salmon do not find it necessary to travel far from the point of the coast at which they emerge; hence, by taking the nearest river mouth at the proper time, they naturally find their way to the head of the stream in which they were hatched.

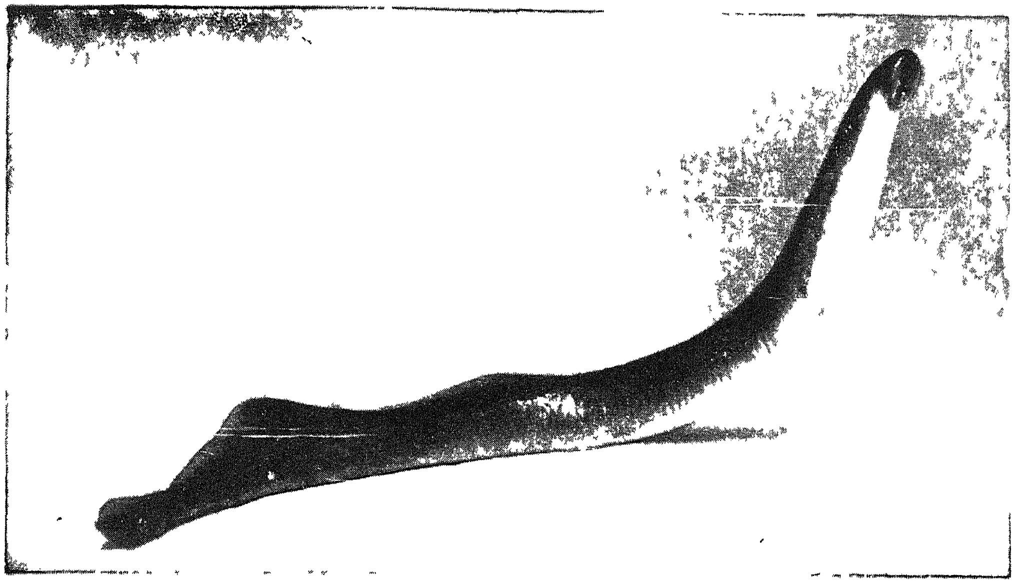
Many a salmon, of course, ends its days without ever returning to reproduce, for the stages from egg to parr and through to adult are teeming with dangers of every description. In order to insure a larger salmon harvest many countries have established hatcheries for the purpose of artificially propagating these noble fish. In the hatcheries fertile females are stripped of their ova, which are then mixed with the milt taken from the males. The fertilized eggs, fry and fingerlings are carefully tended, and when these periods of naturally high mortality have been passed, the young salmon are released. Notwithstanding this early protection estimates indicate that of every thousand young salmon released from the hatchery only three return as mature fish. The result seems meager, but when we realize that each female salmon produces a thousand eggs for every pound of her weight the possibilities of increase become very great.

Salmon and trout, which are next to be considered, are very similar, and it is of interest to note that male trout will follow a spawning salmon and, if the male salmon is not on guard, fertilize her eggs. Hybrid females formed in this way are less fertile than normal types, and the hybrid males are completely sterile.



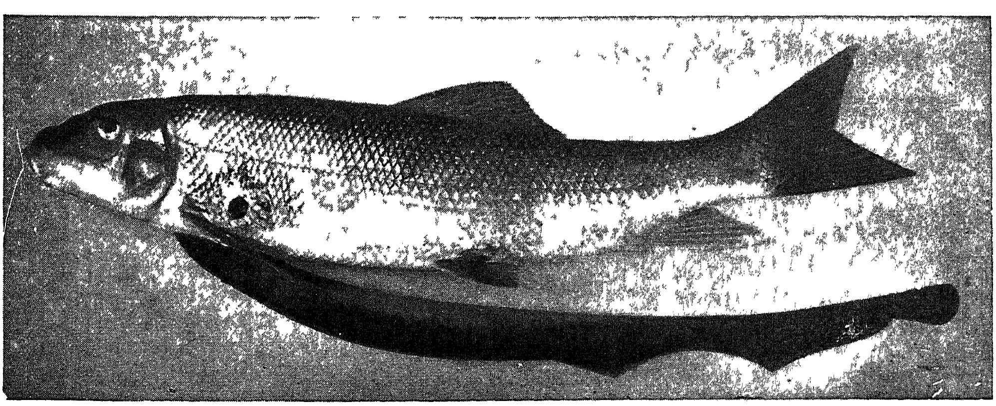
N Y Zoological Society

The rainbow trout, like the salmon, is a member of the highest order of fishes (Teleostei), but it shows some primitive features in its large upper jaw and in the posterior position of the pelvic fins.



THE STRANGE LAMPREY THAT WAS LONG REGARDED AS A FISH

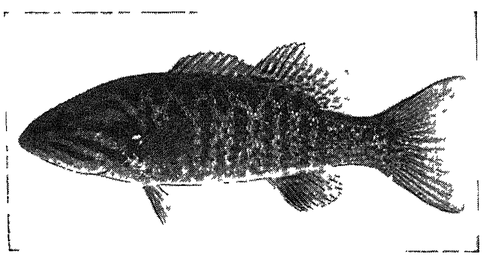
In many respects the trout, as to certain of its species, resembles the salmon in habits. Notably is this the case with regard to sea-trout, or salmon-trout, a fish which descends to the sea to feed, and makes the river its breeding ground All trout, save those confined to lakes, are migratory, and even these latter, if they are to multiply, must have access at spawning time to a stream, naturally or artificially furnished. High opinion holds that the sea-trout, the migratory river-trout and the various lake-trout are all varieties of one race. The famous Loch Leven trout is regarded as marking the transitional type between sea-trout and river-trout. Sea-trout have been landed weighing nearly 30 pounds, and now and again common trout have been brought to scale to show figures almost as surprising. These are, of course, exceptional weights, and the trout of from a pound to a pound and a half is ample enough to be the hero of many an angler's story. Trout kept in lakes and regularly fed seldom attain more than about 10 pounds, even though they may live as long as fifty years The voracity of the trout is not as a rule emphasized, writers preferring to reserve the term for the pike. But the great lake-trout certainly runs the pike close in the matter of appetite and capacity of swallow.



LAKE LAMPREY AND COMMON WHITE SUCKER ON WHICH IT WAS CAUGHT
Note the scars made by the lamprey behind the pectoral and ventral fins of the sucker

And even the common trout is no strainer at trifles. One was caught which had swallowed a field-mouse 2½ inches long.

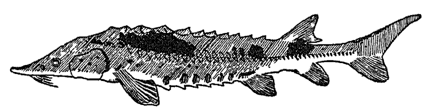
The best known trouts are those comprising the group known as "charrs" and distinguished from others by the presence of red spots on the sides of the body. Among the charrs are found the brook or speckled trout, widely distributed, the sunapee trout of Maine and New Hampshire, the Dolly Varden trout of the West Coast, the sabling of Europe, the lake-trout and numerous others. The brook-trout is one of the most beautiful, active and gamy of fresh-water fish. They thrive only in the cold, swift-flowing



SMALL-MOUTHED BLACK BASS

streams, where they voraciously devour any form of animal-life coming within their reach but preferring crustacea and various forms of insect larvæ The breeding season begins in the latitude of New York and New England about the middle of October and May, continuing into the first days of December. North of this latitude the spawning begins earlier, and south does not occur until later. As with other fishes the dates are based upon temperature rather than the calendar — always spawning with a falling temperature. At this period they push up toward the head-waters of the stream where there is an abundance of gravel though the water be shallow. A gravel bed is necessary to spawning and the successful development of the eggs. Over such a bottom the female prepares a shallow basin-like area by brushing out the sand and gravel with her tail and nose. When the nest is prepared the eggs are deposited and immediately fertilized by the male. The rapidity of development varies from 50 to 125 days according to temperature.

The sturgeon tribe, to which we now pass, is an ancient type of fish, armed with bony covering, as all fish were once armed. Included in the order are the large spoon-bill sturgeons of the Mississippi, whose flesh is smoked and roe sold as imitation caviare; the sword-bill sturgeon of the great Chinese rivers; the toothless sturgeons and other genera. The family of toothless sturgeons, of which the true sturgeons constitute a genus, are of immense importance to the Danube, the Volga and other European rivers. They are sought for their flesh and for their air-bladders, from which isinglass is made, but chiefly, of course, for the roe of the female, from which caviare, the much-appreciated Russian table delicacy, is made. Commonly growing to ten feet, and capable of twice that size, the sturgeon is extremely prolific, the adult female producing three million eggs in the course of a single season. It is this remarkable fecundity that has kept the sturgeon in existence, for no fish is more persecuted by man. When we read of 15,000 sturgeon being taken in the course of a day at a single fishing-station on the Volga, we can readily believe that a river 400 feet in width and 25 feet deep has been known to become completely blocked by a solid mass of these fish.

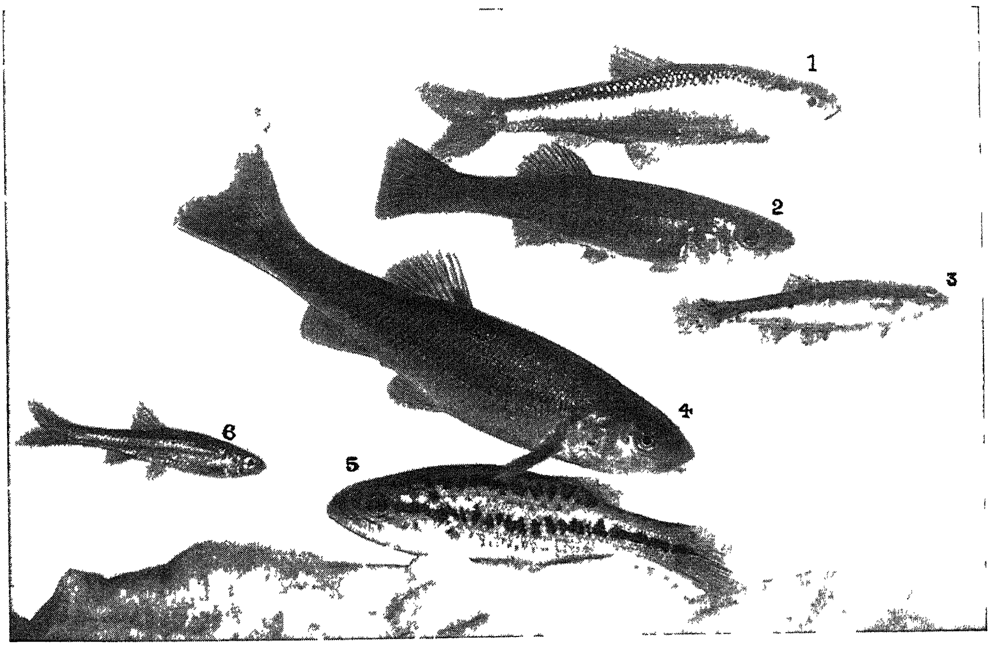


ROCK STURGEON

The rock sturgeon was formerly quite common in the larger waters of the Great Lake region. In recent years they have become much reduced in numbers and are accordingly much less frequently met with. The size of individuals does not equal that of former years. At one time a weight of 100 pounds and upwards was not considered unusual. At present less than 15 pounds will probably cover the bulk of individuals caught. The flesh is smoked and the roe is made into caviare, both ranking high among such articles of food. The spawning of this species takes place early in June in shallow rocky waters along shore.

Jumping the chasm which divides the sturgeon from the pike, we come next to this pirate of the river, the lake and the pond. Pike are widely distributed throughout the majority of rivers of the three northern continents. They are long-lived fish, and attain great size and bulk, specimens having been caught up to 50 pounds weight. This, however, is the exceptional fish, for a list published some time ago showed nothing heavier than 38 pounds. Even that is a considerable fish when it is remembered that the food supply of our rivers is necessarily limited. But the pike is no finicking epicure. He eats anything, from his own kin to rats and waterfowl. He lies like a log in the water, with whose weeds and shadows his coloring perfectly harmonizes, and then at the right moment makes one terrific dash, and there is an end of his victim. Armed with terrible teeth, one series of which are recurved and hinged like those of the snake, the pike's mouth is a death-trap from which there is no escape. The victim must go forward down its captor's throat; the action of the collapsible teeth makes this inevitable.

Pike are very destructive in salmon and trout streams, and as they are prolific — an adult female lays nearly 600,000 eggs — the number of fish they consume is enormous. The well-armed stickleback, whose prickles are commonly proof against the teeth of the greater fish, appears to be the only little creature to which nature has granted a charter of emancipation from the terrors of pike-infested streams, and the perch manages to hold its own. Pike are among the first fishes to spawn in the spring, — making their way into the shallow, plant-grown stretches as soon as the ice is gone and scattering their eggs broadcast where, attached to plant stems, they are left to develop.

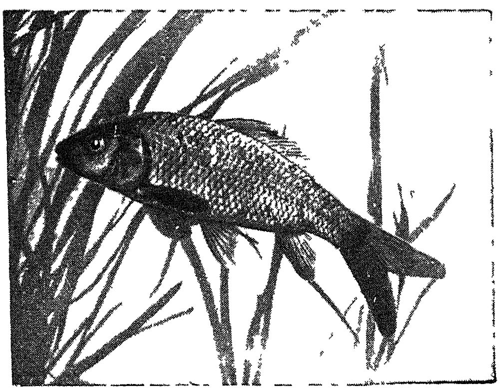


1 COMMON SHINER
2. GRAY-BACK (KILLIFISH)
3. BLACK-NOSED DACE
4 CREEK CHUB
5 YOUNG LARGE-MOUTHED BLACK BASS
6 BLACK-CHINNED MINNOW

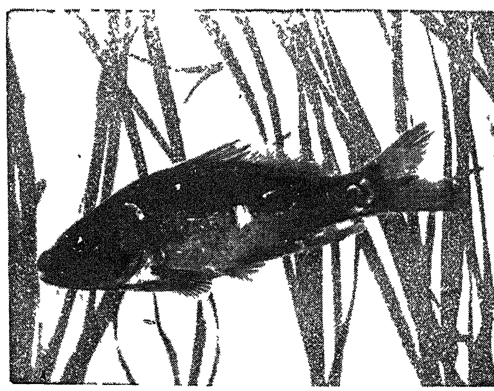
We must pass over other well-known fresh-water fish, such as the dace, the chub, the shiner, the bass, and come next to the carps, of which we have, in various parts of the world, over a hundred genera, divided into two sub-families. The common carp, now a well-established fish in most parts of the northern hemisphere, was brought from China, where it has long been domesticated, to Europe and from Europe to America in 1877. They

are now very broadly distributed in this country. They grow rapidly and may reach a weight under favorable conditions of 30 pounds. There are three varieties: the scaled carp, the body of which is regularly covered by scales; the mirror carp, which is naked except for several irregular rows of very large scales along the back; the leather carp, from which scales are absent entirely.

The popular goldfish is, of course, a carp which has been brought from Asia to the West. Like the common carp, it survives extremes of temperature. This species will thrive in ponds which do not freeze to the bottom during winter and which possess an abundance of the lower aquatic plants. The difficulty of keeping this fish free from fungus in captivity is a



THE COMMON CARP



THE LEATHER CARP

problem which all of us have had to face. Many experiments have been tried, and success seems at last to have been achieved. A weak solution of copper sulphate — one part in 5,000,000 — has been successfully tried for the eradication of the green and brown algæ, which render such waters offensive and unwholesome. The cure for the algæ proved also a cure for the fungus on the fish, which, previously badly attacked by this parasite, were afterwards found to be wholly free from it. A tablespoonful of salt poured into the aquarium jar and allowed to stream down over the infested fish will also kill the fungus, which is a species of *Saprolegnia*.

The notion is prevalent that fishes of whatsoever kind scatter their eggs, leaving the young without aid to make the best of the world as they find it. Fish studies of the past decade have revealed the astonishing fact that a great many species, from both fresh and salt water, have the parental instinct developed to a very high degree. Not only do they protect the eggs but they build a nest for their reception and care for the young during a shorter or longer period after hatching. Thus the common catfish at the breeding season early in summer resorts to some muddy bank where a hole is excavated. The bottom of this is basin-shaped and in it the eggs are deposited and fertilized. After this process is completed the female departs, leaving the male to guard the eggs from intruders and see to it that every particle of sediment is kept carefully brushed away. After hatching the young fish are led away into the pond or stream by the parent, who guards and conducts them as a hen her chickens.

The most perfect nest is that constructed by the sticklebacks. It is made of fine vegetable fibers woven and fastened together in such a fashion that it would do credit to the most fastidious of birds. Two openings are formed in the sides of the nest, one serving as an entrance, the other as an exit. The male constructs the nest and then goes forth in search of a mate. Having found a gravid female he compels her, by no gentle means, to enter his nest and deposit her eggs whether she wills or no. Later she is driven away and the male enters and fertilizes the eggs, after which he searches for another female who in turn is compelled to deposit eggs

This is repeated several times. After the nest is full, no fish, big or small, is allowed to approach within a certain radius.

Many other examples of parental care among fishes might be mentioned, such as the bowfin, pumpkin seed, black basses, shiner and others, all of which excavate shallow basins near the shore or at least in shoal water, where the eggs are deposited and cared for. Usually it is the male which assumes these domestic duties and at this period he becomes very courageous and even pugnacious.

Our chapter must close with the story of the eels. There are very few stretches of fresh water which do not harbor these fish; there is no tidal river which does not bear its prodigious harvest every year of young eels, or elvers, coming up from the sea. We find eels in wells, in running streams, in ditches and dykes; we find them in field-ponds far from rivers. It was impossible to account for their presence. The young of the eels were met at sea, but they were regarded as a distinct genus of fish, and were given the name of *leptocephali*, while no one knew how the big eels at home perpetuated their species. The story is out at last. The huge eels which are known to have spent many years in ponds, tanks and wells are the bachelors and spinsters. Those that vanish and are seen going down-stream to the sea are the potential progenitors of the generations to be. It would seem that some eels, though they may attain great age and bodily bulk, do not attain sexual maturity; they remain in their ponds. Others, of course, may find it impossible to escape from the prison in which they have incarcerated themselves. But when sexual impulses impel the adult eel which is in such a position that it may escape to the sea, to the sea the eel goes. Eels spawn in the ocean and die. The adult never returns to the fresh water from which it set out. A mature female eel may produce over ten million ova. The production and fertilization of these vast numbers exhaust the vitality of the adults, and they expire at the end of the spawning season. The larvæ undergo a remarkable series of metamorphoses. The familiar transparent outline of the little fish, with sharp-snouted head, which earned a distinct name, gradually yields place to the cylindrical form of the elver. It is believed that these changes take a year, and that at the end of that time the tiny mites of life set out for the rivers. They are equipped with specially modified gills which retain moisture, and enable them to accomplish journeys over land fully as remarkable as those of the climbing perch. They climb lock-gates; they worm their way through sluices and pipes and all manner of mechanical obstructions; they take to the land, and wriggle like tiny snakes across the dewy grass, to where instinct tells them water is to be found. That is the manner in which isolated ponds and water-holes get their eel supply. The damage

THE COMMON EEL

done by eels to the rest of the fish-life of our rivers is inestimable. Not only do they attack little fish and big; they consume enormous numbers of ova. They do not limit themselves to a fish diet, but are omnivorous.

Our common eels are related to the savage murænas, of which some four-score species are distributed over all tropical and temperate seas and the mouths of certain tidal rivers. An interesting eel is the "amphibious eel" of Bengal, in which there is an accessory breathing-sac, enabling it to breathe atmospheric air.

There we must leave the fishes. The sketch is incomplete, but it may serve to point a track along which the student may find the whole wide subject accessible and interesting, and lure him to investigations beside both running and quiet waters.

In the nineteenth century there was unparalleled progress in almost every field of pure and applied science.

Science and Progress (1815-95) I

by JUSTUS SCHIFFERES

THE SPIRIT OF PROGRESS

BY 1815 the Bourbons were back in power in France. (They were to remain in power for only fifteen years.) The struggling American colonies had become the lusty United States of America, and this young country was pushing its frontiers ever westward. The Western world now prepared to enjoy the fruits of the French, American, Industrial and Chemical revolutions in a century of comparative peace. Note well the word "comparative." There was no dearth of wars in the nineteenth century after the final collapse of Napoleon's empire in 1815; there were revolutions, too, in many lands — Spain, France, Italy, Greece, Hungary, Latin America. Yet, with the exception of America's bloody war between the states, there were no long-drawn-out struggles, like the War of the Spanish Succession, the War of the Austrian Succession, the Seven Years' War and above all the Napoleonic Wars, which had drained the man power and resources of Europe in the eighteenth century and in the first years of the nineteenth.

If we may choose one word to describe the spirit of the nineteenth century, that word is "progress." There was a general belief that after long stumbling, the world was at last "getting somewhere." There was progress in the political field; there was a powerful upsurge of political liberty and democracy. The last vestiges of serfdom were annihilated in Russia and Prussia; the United States put an end to slavery; there was electoral reform in Britain; Italy and most of the Balkan states were freed from foreign masters. Science and technology, too, were wedded to the idea of progress. There was visible evidence of this fact in continuing triumphs over space (the steamboat and railroad), distance (the telegraph, telephone and cable), discomfort (anesthesia) and even death (the germ theory of disease, aseptic surgery). "I doubt not through the ages one increasing purpose runs," sang Alfred Tennyson, England's poet laureate.

All sciences made notable advances in the nineteenth century. To be sure, the path of the scientist, as in every age, was strewn with difficulties. Patient, plodding, brilliant, idea-ridden men and women gave up years of their lives in out-of-the-way laboratories; their experiments all too often ended in failure. Nature still did not yield her secrets easily. But the value of persistent research in the study of natural phenomena took hold, more and more, of men's minds. The results were spectacular. In chemistry, physics, astronomy, biology — in fact, in practically every field of science — there were amazing advances.

So rapid was scientific progress in the nineteenth century that by the end of it many scientists came to believe that the basic foundations of scientific theory had been laid down once and for all. What remained, they thought, was simply to make more exact measurements and to fill in existing gaps in scientific knowledge. The enthusiasm for the scientific method was carried over into many other fields. Thus a great French scholar, Hippolyte Taine (1828–93), thought of history and literary criticism as sciences that were just as exact as chemistry and physics. The materials for Taine's notable historical and critical works were made up, to quote his own words, of "little facts, well chosen, im-

portant, significant, amply substantiated, minutely noted."

We realize now that some of the scientific "certainties" of the nineteenth century were not nearly so certain as it was then believed. New discoveries in the last few years of the century and in the twentieth century brought about radical changes in many basic ideas. Yet all men of science join in paying tribute to the solid scientific achievements of the nineteenth century. Let us examine these achievements.

CHEMISTRY COMES OF AGE

In the almost fabulous "century of progress" no science made greater strides than chemistry. It is impossible to mention here all the men who contributed to this rapid advance, for names now come thick and fast. The new chemistry, rapidly growing in strength, soon splintered into many important and useful chemical specialties, including, for example, electrochemistry, organic chemistry, inorganic chemistry, agricultural chemistry, physical chemistry and stereochemistry.

The work of Black, Cavendish, Lavoisier and other giants of the Chemical Revolution had shown that exactness was possible in dealing with chemical reactions. Chemists could now obtain substances that were chemically pure — that is, untainted with other substances — to a high degree of accuracy. By using such chemically pure materials, the French chemist Joseph-Louis Proust (1754–1826) was able to show that every compound, however formed, whether found in nature or artificially made in the laboratory, always contained *the same elements combined in the same proportions by weight.* This law of definite proportions is a cornerstone of chemical teaching.

Now came a color-blind Quaker schoolteacher in Manchester, England — John Dalton (1766–1844) — to put the science of chemistry on a still firmer foundation. Earlier, Dalton had been particularly interested in the phenomenon of color blindness (sometimes called Daltonism after him). He had also begun to keep a meteorological diary (notes on weather), in which he made over 200,000 observations in the course of his long lifetime. His chemical theories were summed up in his classic work A NEW SYSTEM OF CHEMICAL PHILOSOPHY, in three volumes. The first volume was published in 1808.

Dalton turned to the concept of matter that had been held by Democritus and certain other philosophers in antiquity: the notion that all things are made up of indestructible particles called atoms (see page 239). On better evidence than the ancients, he came to the conclusion that "all bodies of sensible [appreciable] magnitude, whether liquid or solid, are constituted of a vast number of extremely small particles or atoms of matter bound together by a force of attraction which is more or less powerful according to the circumstances."

He now developed the idea of atomic weights. He realized that one could not weigh atoms on scales as one could weigh apples or onions. But he pointed out that it is possible to find the *comparative* weights of atoms of different elements. It is only necessary to select, arbitrarily, a given element as a unit and to determine how much heavier (or lighter) than this unit the other elements are. Dalton chose as his unit the element hydrogen, to which he gave the value 1. Studying the comparative weights of different elements, he came upon the valuable law of multiple proportions: "If two elements combine to form more than one compound, the ratios between the elements in all these compounds will consist of whole small numbers."

Dalton's atomic theory proved exceedingly useful — particularly the idea that chemical reactions take place between particles of different weights. Today, however, we realize that his doctrines were inaccurate in various details. We know now that the atom is far from being the smallest particle of matter. And it is anything but indivisible; it can be smashed

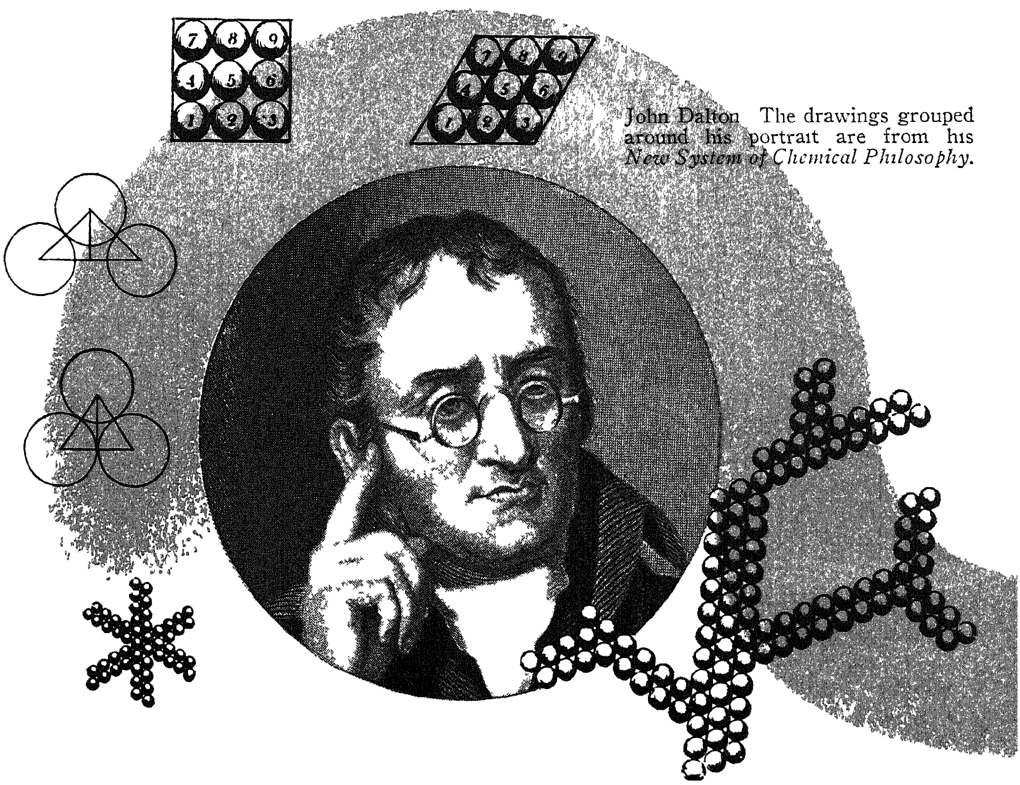
with a vengeance! Furthermore, we now use oxygen instead of hydrogen as the basic unit of the atomic-weight system. We give oxygen the arbitrary value of 16.000, and we calculate the weight of other elements in terms of the weight of oxygen. (See page 310.)

In 1815 the English physician William Prout (1785–1850) introduced an encouragingly simple theory of matter, based on the concept of atomic weights. He held that all atoms are built up of hydrogen atoms and that all atomic weights are multiples of the weight of hydrogen. The very rough atomic-weight values available at the time seemed to confirm Prout's theory. But when chemists succeeded in getting more accurate figures, they rejected Prout's hypothesis outright. They pointed out, for example, that chlorine is about 35½ times as heavy as hydrogen; obviously 35½ is not a multiple of 1! They also scoffed at the notion that all atoms are made up of hydrogen atoms.

Today most chemists acknowledge that there is at least a certain amount of truth in Prout's theory. The discovery of isotopes, in particular, gave it powerful support. An isotope is one of two or more forms of the same element, having different atomic weights. We realize now that the atomic weight of an element is the *average* weight of all its isotopes. In the case of chlorine, the atomic weight of each of its six isotopes is very nearly a multiple of the atomic weight of hydrogen.

Furthermore, the notion that all elements are made up out of hydrogen atoms no longer seems as fantastic as was once the case. For scientists have pretty conclusively shown that the sun's tremendous energy is due to a complicated series of reactions in which four atoms of hydrogen are turned into a single atom of helium. Truly, the "folly" of one generation is the "wisdom" of another.

Dalton had maintained that when atoms combined chemically with one another, they formed what he called "complex atoms." Today we give the name of molecule to such combinations of atoms (from a Latin word meaning "little



John Dalton The drawings grouped around his portrait are from his *New System of Chemical Philosophy.*

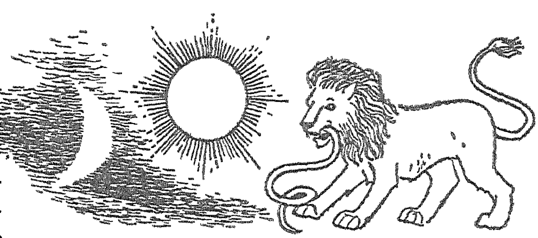
SIR HUMPHRY DAVY

masses"). We define a molecule as the smallest possible quantity of a given substance that retains all the properties of that substance. We can break up a molecule chemically, but in that case we would no longer have the same substance. If, for example, we pass an electric current through water, we can decompose the water molecules; we no longer have water but, instead, two gases — oxygen and hydrogen.

The inventor of the word "molecule" was an unpretentious professor of physics at Turin, Italy—Amedeo Avogadro (1776–1856). He was particularly interested in the molecules of gases. He thought of these particles as widely separated, moving incessantly and constantly bumping into one another and into the sides of the container in which they were confined. Avogadro knew that all gases expand and contract equally when equal changes of pressure or temperature are applied. He came to the conclusion that this is so because equal volumes of gases, under the same conditions of temperature and of pressure contain the same number of molecules. This theory is now known as Avogadro's law, or principle, or hypothesis; it is universally accepted by chemists. In the course of his researches Avogadro estimated the number of molecules in 18 grams of water and arrived at the amazing figure of 602,000,000,000,000,000,000,000. This figure, generally abbreviated to read 6.02×10^{23}, is called Avogadro's number; it is valuable in many different kinds of calculations.

Avogadro's findings, which are a basic part of modern chemical theory, were not widely accepted at first. For half a century or so chemists continued to be confused by the difference between atoms and molecules. Much of this confusion was cleared up at last by the Italian Stanislao Cannizzaro (1826–1910), a revolutionist, chemistry professor and senator. In 1858 he forcefully reintroduced Avogadro's neglected hypothesis and showed that it could serve to help determine the molecular weights of elements and compounds. (The molecular weight of a substance is the combined weight of the atoms making up the molecule of that substance.)

In the meantime the number of known elements was steadily increasing. In 1789 Lavoisier had correctly identified twenty-three elements; by 1813, Sir Humphry Davy (1778–1829) could name forty-seven. Sir Humphry was a brilliant if sometimes haughty and jealous man of science. He was the inventor of the miner's safety lamp and the director of London's Royal Institution, where his showy lectures attracted fashionable crowds of men and women. He was also one of the first men to use the word "science" in its present meaning. Davy and his great pupil Michael Faraday (see page 1927) contributed largely to the budding science of electrochemistry. In fact, Davy isolated certain elements, such as sodium and potassium, by passing a strong current of electricity through moist compounds in which the elements in question occurred.



Three alchemical symbols. The moon stands for silver; the sun, for gold. The lion that is devouring the snake represents an acid dissolving a salt.

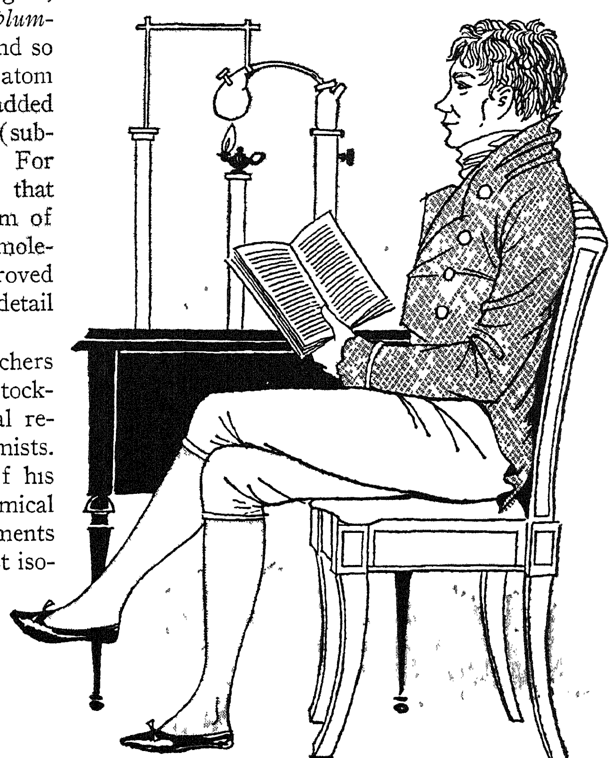
As the number of known elements increased, chemists realized how important it was to find a simple way of expressing them by means of symbols. The old alchemical symbols were clumsy and in some cases downright silly. Dalton proposed a somewhat more sensible system of notation in which each symbol stood for a single atom of a given element. Thus ○ stood for an atom of oxygen, ⊙ for an atom of hydrogen, ● for an atom of carbon, Ⓘ for an atom of iron. To indicate his "complex atoms" Dalton joined symbols together. In his notation, for example, water was indicated by ⊙○ · that is, an atom of hydrogen plus an atom of oxygen. (Actually, there are two hydrogen atoms in the water molecule.)

The great Swedish chemist and teacher (and eventually baron) Joens Jakob Berzelius (1779–1848) now hit upon a far simpler system. In this, he designated elements by the capitalized first letter of their Latin, or Latinized, names, or by the first letter plus one other letter. This system is still in use. In it gold is designated by the letters Au, from the Latin word for gold, *aurum;* lead, by Pb, from the Latin *plumbum;* carbon, by C; calcium, by Ca and so on. The symbol stands for a single atom of an element; a small number is added after and at the bottom of a symbol (subscript) to indicate two or more atoms. For example, the notation H_2O means that two atoms of hydrogen and one atom of oxygen are united to form a water molecule. This chemical shorthand has proved very useful; we describe it in greater detail on pages 644-45.

Berzelius was one of the great teachers of his generation; his laboratory in Stockholm was a headquarters of chemical research and a Mecca for aspiring chemists. His notation system was only one of his many important contributions to chemical knowledge. He discovered the elements selenium, cerium and thorium and first isolated several others. He developed the idea that certain groups of atoms, called chemical radicals, could go through a series of reactions without change — for all the world as if each radical were an element. He called attention to chemical catalysts, substances which "arouse the slumbering affinities of other substances" but which do not themselves take part in the final chemical reaction.

Like many other great scientists, Berzelius sometimes supported theories that later proved to be false. Among these was the notion that there is a fundamental difference between organic (living) matter and inorganic (dead, or inanimate or lifeless) matter. Like most of his contemporaries, Berzelius held that there is a "vital force" in organic substances and that this force is totally lacking in inorganic materials. He maintained that it would be impossible for man to duplicate this "vital force"; therefore, it would be forever impossible to create an organic compound in a chemical laboratory.

This dictum was given the lie in 1828.



JOENS JAKOB BERZELIUS

In that year a gifted young German chemist, Friedrich Woehler (1800–82), did precisely what Berzelius had declared to be impossible. By heating a combination of two inorganic compounds — cyanic acid and ammonia — he succeeded in producing urea, an organic compound that occurs in urine. Of this achievement the eminent chemical historian Thomas E. Thorpe (1845–1925) wrote as follows: "That . . . should be accounted a red letter day in the history of science . . . By demonstrating that urea can be made synthetically by ordinary laboratory processes and from substances inorganic in their origin, Woehler proved that vital force is only another name for chemical action, and that an animal is nothing but a laboratory in which a multitude of chemical changes, similar to those which occur in our test tubes . . . is continually taking place." Thorpe was exaggerating, indeed. While it is true that the chemist can analyze such processes as metabolism in great detail, animal bodies are no more chemical laboratories than they are machines (as the Cartesians had claimed two centuries before).

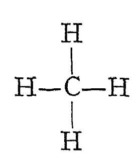
Woehler's epoch-making discovery did not have immediate results. It is true that, in the years that followed, other organic substances were occasionally produced in the laboratory; but there was no systematic effort to produce so-called organic compounds until after the middle of the nineteenth century. This did not mean, however, that research in organic chemistry — the study of organic compounds — lagged in the meanwhile. As a matter of fact, a number of striking discoveries put this branch of chemistry on a firm basis and made possible the spectacular advances of the second half of the century.

Certainly the study of organic substances was in a chaotic state in the first few decades of the nineteenth century. It was clear enough that such materials were all compounds of the element carbon; it was clear, too, that for the most part they were made up of carbon, hydrogen and oxygen, with occasional atoms of other elements, such as nitrogen, phosphorus and sulfur. But the atoms of these different elements seemed to combine in the most haphazard sort of way. In 1835 Woehler wrote despairingly to Berzelius: "Organic chemistry just now is enough to drive one mad. It gives me the impression of a primeval tropical forest, full of the most remarkable things — a monstrous and boundless thicket, with no way to escape, into which one may well dread to enter." It was the task of Woehler and of other devoted organic chemists to hew a way through this "primeval forest."

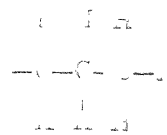
The French chemist Charles-Frédéric Gerhardt (1816–56) made a start by classifying organic compounds into a definite number of types. He also introduced the idea of homologous series, made up of a certain number of members. The molecule of each member contains one carbon atom more and two hydrogen atoms more than the molecule of the preceding member. Methane (CH_4) and ethane (C_2H_6), for example, are two neighboring members of a homologous series. Note that ethane has one more carbon atom and two more hydrogen atoms than methane.

Another great step forward was the introduction of the doctrine of valence by the Englishman Edward Frankland (1825–99). This doctrine accounts for the way in which atoms are combined in a molecule. For example, a hydrogen atom can be linked to only one other atom: it is said to have a valence of one. When a carbon atom is linked to four atoms, it is said to have a valence of four. In the molecule of methane, for example, one atom of carbon is linked to four atoms of hydrogen. (In some cases carbon has a valence of two.)

Later the linking of atoms came to be represented by what is called a graphic formula. In this the links, or bonds, between different atoms are indicated by short lines. Here is the graphic formula of methane (CH_4):



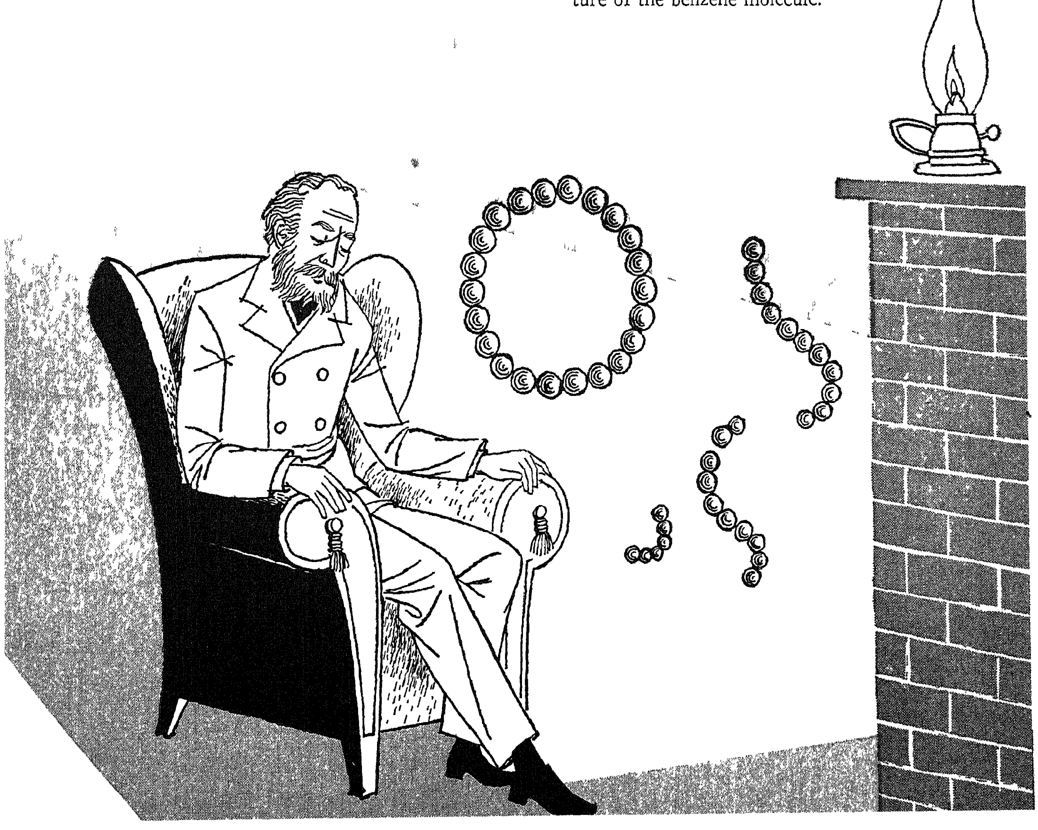
Chemists came to realize that many organic compounds were built up of chains of carbon atoms linked to other atoms. The chainlike arrangement of the propane molecule, which has three carbon atoms and eight hydrogen atoms, is clearly shown by its graphic formula:



This arrangement is also indicated by the simplified form of graphic formula that is called the structural formula. The structural formula of the propane molecule, above, is $CH_3CH_2CH_3$.

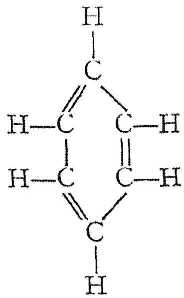
One group of organic substances — the so-called aromatic compounds — baffled chemists for a long time. For these compounds never contain less than six carbon atoms; yet it was impossible to arrange them in a chain. For example, the molecule of the aromatic compound benzene consists of six atoms of carbon and six atoms of hydrogen. There are not nearly enough hydrogen atoms to form a chain pattern.

This problem had aroused the interest of the German chemist Friedrich August Kekule (1829–96). One autumn evening in 1865, as he sat dozing before the fireplace, it seemed to him that he saw great numbers of atoms gamboling before him. According to his account, he was particularly struck by certain groups of atoms, "all twining and twisting in snake-like motion. But look! What was that? One of the snakes had seized hold of its own tail, and the form whirled mockingly before my eyes. As if roused by a flash of lightning, I awoke." Amazingly, this vision gave Kekule just the clue he needed to divine the structure of the benzene molecule. For



Kekule's dream, which gave him the clue to the structure of the benzene molecule.

he pointed out that it is a closed ring of six carbon atoms, to each of which a hydrogen atom is attached, thus:



While the mysteries of organic compounds were being solved, the organic chemist Justus Liebig (1803–73) had laid the foundations of agricultural chemistry and, to some degree, of physiological chemistry as well. Liebig, an impressive figure in the chemical world of the 1830's and 1840's, was the founder of a famous teaching laboratory at Giessen, opened in 1826. The spirit in which Liebig and his students pursued their chemical studies may be gleaned from his description of those early days. "At Giessen," he wrote, "all were concentrated in the work, and this was a passionate enjoyment . . . A kindly fate had brought together in Giessen the most talented youths from all countries of Europe . . . Everyone was obliged to find his own way for himself . . . We worked from dawn to the fall of night."

Liebig traced the nitrogen cycle. He taught that plants get carbon and nitrogen from the carbon dioxide in the atmosphere and from nitrogen compounds formed from atmospheric nitrogen; he pointed out that carbon dioxide and nitrogen are gradually returned to the atmosphere after the plants die. He demonstrated that plants derive other nutritive substances, such as potash, lime, soda, phosphorus and sulfur, from the soil. He attempted to show how chemical and physical laws operate in the human body; he demonstrated, for example, that body heat is the result of the combustion of foods within the body.

In the second half of the nineteenth century many chemists turned to the synthesis of organic compounds. Much of their research was focused on coal tar, a derivative of coal. Through their efforts this gummy, ill-smelling substance became one of the most precious raw materials of the industrial chemist.

In the early years of the nineteenth century, coal tar was a useless by-product in the manufacture of coal gas used for illuminating purposes. As time went on, some of the coal tar was burned as fuel, a certain amount was distilled, and the "spirit" obtained in this way was used as a substitute for turpentine or as a solvent for rubber. But on the whole, coal tar was not considered to be a particularly valuable substance.

It was the young English chemist William H. Perkin (1838–1907) who first showed its amazing possibilities as a starting point for the manufacture of whole classes of synthetic chemicals. In 1856 Perkin, a lad of eighteen, tried to produce quinine in the laboratory. He used coal tar as a base, but he was entirely unsuccessful. (As a matter of fact, quinine was not synthesized until 1944.) In the course of his experiments, however, Perkin made a momentous discovery: he found that a synthetic dye — mauve purple — could be prepared from coal tar. Perkin and his family quickly set about producing this synthetic dye on a commercial scale. Soon Perkin stumbled upon a second synthetic dye, magenta. Later, he gave up manufacture and devoted himself to research.

A synthetic dye that made the madder plant valueless

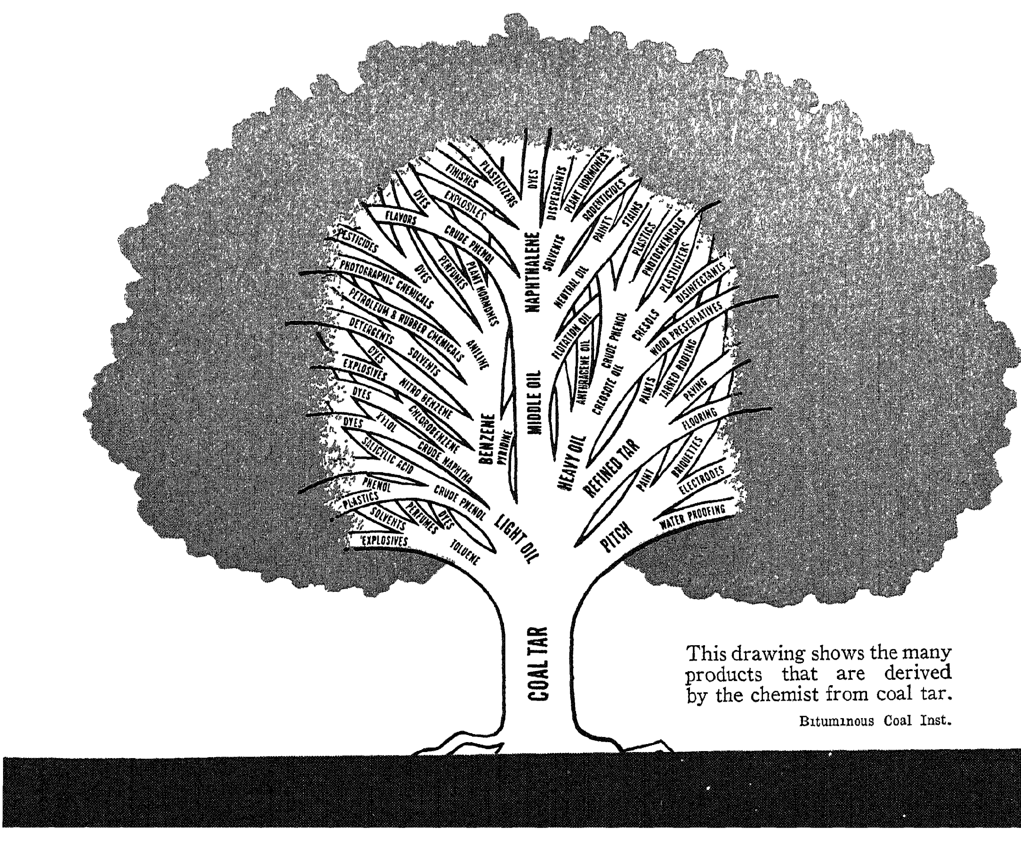
In 1868, two German chemists, Karl Graebe (1841–1927) and Karl Theodor Liebermann (1842–1914), started with anthracene, one of the muddiest fractions that is left in the distillation of coal tar, and they succeeded in synthesizing the dye known as alizarin, or Turkey red. For many hundreds of years this red dye had been obtained from the root of the madder; in 1868, this plant was being profitably cultivated in France, Holland, Italy and Turkey. Almost overnight a long-established agricultural product was ren-

dered valueless as the result of a triumph in organic chemistry. (But organic chemistry, drawing some of its materials from the products of the farm, has since given increased importance to other crops, such as sugar-beets and soybeans.)

A prominent German chemist, Adolf von Baeyer (1835–1917), worked industriously on the synthesis of the blue dye indigo. He obtained the structural formula for this dye as early as 1880; but many problems had to be solved before it could be profitably manufactured and marketed. In the meantime Baeyer and his co-workers succeeded in producing a synthetic drug, aspirin, a compound of salicylic acid. The relation between dyestuffs and drug stuffs is closer than you may think. As we shall see later, the parent substance of our famous sulfa drugs was originally intended to be a red dye!

As time went on, dyes representing almost every shade of the rainbow were produced synthetically, and a vast dye industry was developed. Organic chemists also succeeded in preparing various synthetic drugs. We have already mentioned aspirin. Among the other synthetic drugs produced in the nineteenth century were antipyrine, used to reduce fever, and phenacetin, an analgesic (pain-killing) drug. Synthetic perfumes were also created. Perkin, the first chemist to synthesize a dye, was also the first to prepare synthetically a perfume found in nature — coumarin. Since that time many other perfumes — vanillin, meadow sweet, hawthorn blossom and oil of wintergreen, among others — have been synthesized.

A decisive triumph of the organic chemist in the nineteenth century was the production of dynamite. In 1845 a German chemist, Christian Friedrich Schoenbein, had discovered that cotton saturated with nitric acid — guncotton — was a high explosive. In the following year the Italian Ascanio Sobrero had prepared a substance called nitroglycerin, which for some time thereafter was used only in medical practice as a heart stimulant. The Swedish



This drawing shows the many products that are derived by the chemist from coal tar.

Bituminous Coal Inst.

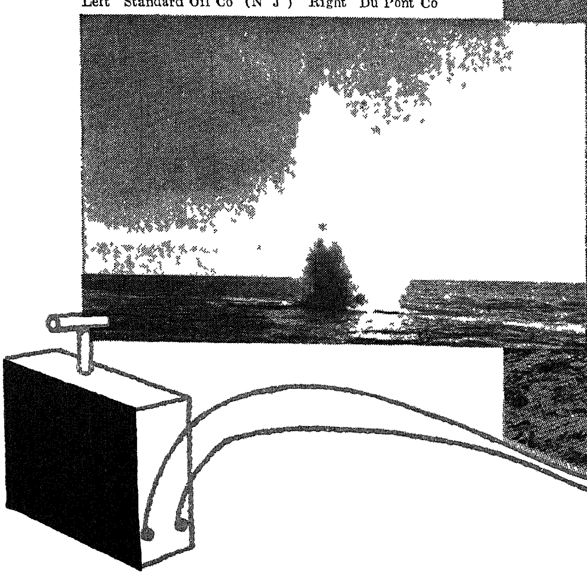
engineer, inventor and philanthropist Alfred Nobel (1833–96) created a powerful and easily handled explosive in 1867 by mixing guncotton and nitroglycerin and by "gentling" the mixture with porous clay. Nobel gave the name "dynamite" (from the Greek *dynamis,* meaning "power") to this substance. People generally think of dynamite as an agent of destruction. But it has also served to lighten men's tasks in quarries and mines and in the construction of tunnels and bridges.

Upon his death, in 1896, Nobel bequeathed a sum of approximately $9,000,000 for the purpose of awarding annual prizes in chemistry, physics, medicine and physiology, literature and the promotion of peace. We discuss these Nobel awards on page 4129.

There was great progress in physical chemistry in the nineteenth century. The name of this science indicates its nature, for it stands on the borderline between physics and chemistry. Classical physics deals with the different forms of energy and the physical changes that they bring about in matter. (For the difference between physical and chemical changes, see pages 643-44.) Chemistry is particularly concerned with the composition of matter and the chemical changes that it undergoes The physical chemist studies the relations between the *physical* and the *chemical* prop-

ALFRED NOBEL

Left Standard Oil Co (N J) Right Du Pont Co



erties of a great variety of substances

We can only sketch briefly here the advances made in physical chemistry in the age of progress. Sir Humphry Davy and Michael Faraday did yeoman pioneer work in electrochemistry. The Danish chemist Julius Thomsen (1826–1909) and the French chemist Marcelin Berthelot (1827–1907) made valuable contributions to the study of thermochemistry: the study of the heat effects accompanying chemical reactions. The advances in photochemistry — the study of the chemical changes produced by light radiation — made modern photography possible. In 1861 Thomas Graham, a Scottish chemist, laid the foundations of colloid chemistry (see pages 1989-98). A shy, unassuming bachelor professor of mathematical physics at Yale College — Josiah Willard Gibbs (1839–1903) — worked out the relation between chemical, electrical and thermal energy. A flood of light was thrown on the phenomenon called osmosis (see Index, under Osmosis) by the Dutchman Jacobus Hendricus van't Hoff (1852–1911); he also founded the science of stereochemistry — the study of the arrangements of atoms in space. A Swedish professor, Svante August Arrhenius (1859–1927), studied the problem of the formation of ions (charged particles) in solutions conducting electricity; he worked out a formula for measuring the concentration of ions in such solutions.

The work of these men stressed a point that had sometimes been overlooked in the haste of nineteenth-century progress — that physics and chemistry and, indeed, all the sciences are interdependent.

One of the most significant of all the theoretical developments in the nineteenth century was the demonstration that chemical elements fall into certain more or less clearly defined groups. We shall discuss this periodic classification of the elements, as it is called, in the following pages

THE CLASSIFICATION OF THE CHEMICAL ELEMENTS

For years after the modern concept of chemical elements was introduced, the elements were thought to be "mere fragmentary, incidental facts in nature," to quote the eminent Russian chemist Dmitri Mendeleev (1834–1907). It was Mendeleev's principal claim to fame that he revealed the fixed relationship between the atomic weights of the elements and their chemical and physical properties. This is one of the basic concepts of modern chemical theory.

The idea, indeed, was not completely original with Mendeleev. Not long after Dalton had introduced his theory of atomic weights, a German professor, Johann Wolfgang Doebereiner (1780–1849), had grouped a few sets of elements in threes (triads). The atomic weight of one of the elements in each triad was about equal to half the combined atomic weights of the other two elements. Among the triads were chlorine-bromine-iodine and calcium-strontium-barium.

In the year 1865 the young English chemist John A. R. Newlands (1837–98) proposed a radically new sort of arrangement in which the elements known in his time were grouped mainly in the order of their atomic weights. In Newlands' arrangement, given on the next page, the letters are the symbols of the elements (see page 4123); the numbers represent the order in which the elements occur on the basis of their atomic weights.

Brown Bros

Dmitri Mendeleev, one of the greatest of modern chemists

H 1	F 8	Cl 15	Bo, Ni 22	Br 29	Pd 36	I 42	Pt, Ir 50
Li 2	Na 9	K 16	Cu 23	Rb 30	Ag 37	Cs 44	Tl 53
Gl 3	Mg 10	Ca 17	Zn 25	Sr 31	Cd 38	Ba, V 45	Pb 54
B 4	Al 11	Cr 19	Y 24	Ce, La 33	U 40	Ta 46	Th 56
C 5	Si 12	Ti 18	In 26	Zr 32	Sn 39	W 47	Hg 52
N 6	P 13	Mn 20	As 27	Di, Mo 34	Sb 41	Nb 48	Bi 55
O 7	S 14	Fe 21	Se 28	Rh, Ru 35	Te 43	Au 49	Os 51

Newlands' classification of the chemical elements.

Newlands held that the elements that appear on the same horizontal line in the above table are related. Thus the eighth element, fluorine, has properties like the first, hydrogen; the fifteenth, chlorine, has properties like the first and the eighth. Newlands gave the name octaves to his units of eight elements. "There is a kind of repetition," he said, "like the eighth note of an octave of music." Another name for such a repetition of characteristics is periodicity; an arrangement of this sort is called periodic.

Newlands' classification made no allowance for the elements still to be discovered; in some cases, too, dissimilar elements were placed in the same octaves. Reputable chemists, therefore, scoffed at his theory.

But only three or four years later, Mendeleev and the German chemist Julius Lothar Meyer (1830–95), working independently, showed that Newlands had been on the right track. For modifying greatly the too simple arrangement of Newlands, they demonstrated that there is indeed a natural classification of the elements. Since Mendeleev gave the more comprehensive account of this theory, it is generally associated with his name.

Lecturing in London in 1869, Mendeleev drew attention to the following propositions:

1. The elements, if arranged according to their atomic weights, exhibit an evident periodicity of properties.

2. Elements that are similar as regards their chemical properties have atomic weights that are nearly the same value (as, for example, platinum, iridium, osmium) or that increase regularly (as, for example, potassium, rubidium, cesium).

3. The arrangement of the elements, or groups of elements, in the order of their atomic weights corresponds to their so-called valences (combining values) as well as, to some extent, to their distinctive chemical properties . . .

4. The elements that are most widely diffused have small atomic weights.

5. The magnitude of the atomic weight determines the character of the element, just as the magnitude of the molecule determines the character of the compound.

6. We must expect the discovery of many yet unknown elements . . .

7. The atomic weight of an element may sometimes be amended by knowledge of those of contiguous elements . . .

8. Certain characteristic properties of elements can be foretold from their atomic weights.

On the basis of these conclusions Mendeleev drew up a table of the periodic

classification of the elements. On this page we give the table that he prepared in 1871; in this case the numbers stand for atomic weights.

Great changes have been made in the periodic table since it was introduced by Mendeleev (see page 4124). Yet even the most modern versions are based essentially on the Russian chemist's classification.

Mendeleev left certain gaps in his table so that elements with related properties might fall within the same groups. He predicted, as we have seen, that these gaps would be filled in time through the discovery of new elements. Not only did he name three of these unknown elements (he called them "eka-boron," "eka-aluminum" and "eka-silicon"), but he predicted the properties that they would be found to possess. His predictions were brilliantly fulfilled. In 1875 the Frenchman Paul-Emile Lecoq de Boisbaudran (1838?–1912) found an element that answered to the description of "eka-aluminum"; he patriotically gave it the name of gallium (from Gaul, the ancient name of France). Four years later, Lars Fredrik Nilson (1840–99), a Swedish chemist, discovered "eka-boron," which he called scandium (from Scandinavia). Finally, in 1886, the German Clemens Alexander Winkler (1838–1904) turned up the element that Mendeleev had called "eka-silicon"; he named it germanium, after his native Germany.

The search for other new chemical elements went on apace. One of the most valuable tools in this search was spectrum analysis — the investigation of substances by means of their spectra (see Index).

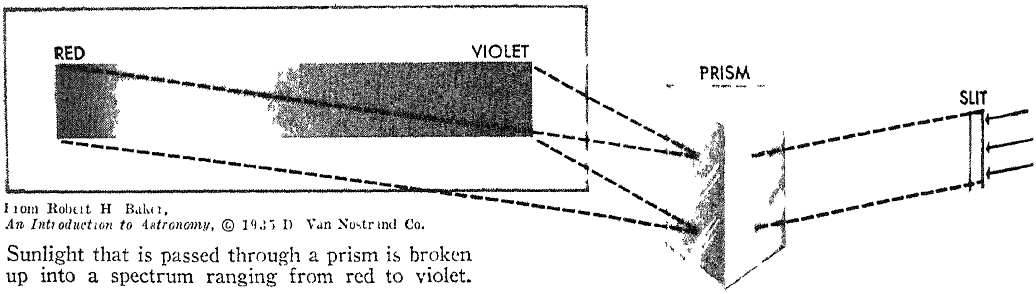
As early as 1752 the Scottish divinity student Thomas Melvill had found that when he passed light from certain incandescent gases through a prism, he saw not the complete spectrum but only certain bright lines. Among other things he discovered the "bright yellow line" that, we now know, indicates the presence of sodium.

In 1802 the London physician William Wollaston discovered certain dark vertical lines interrupting the otherwise continuous colored band of the spectrum. These dark lines were rediscovered in 1814 by Joseph Fraunhofer (1787–1826), a self-educated Bavarian instrument-maker. Though he did not know what these markings represented, he mapped them carefully; they are still called Fraunhofer lines, after his name. This busy man also invented the spectroscope. In this instrument a beam of light is permitted to pass through a narrow slit and to fall upon a prism; after it has been spread by the prism, it is observed through telescopic lenses.

The real meaning of spectral lines was finally revealed in 1859 by two closely as-

Mendeleev's periodic classification of the chemical elements.

	Group I	*Group II*	*Group III*	*Group IV*	*Group V*	*Group VI*	*Group VII*	*Group VIII*
1	H = 1							
2	Li = 7	Be = 9.4	B = 11	C = 12	N = 14	O = 16	F = 19	
3	Na = 23	Mg = 24	Al = 27.3	Si = 28	P = 31	S = 32	Cl = 35.5	
4	K = 39	Ca = 40	— = 44	Ti = 48	V = 51	Cr = 52	Mn = 55	Fe = 56, Co = 59, Ni = 59
5	Cu = 63	Zn = 65	— = 68	— = 72	As = 75	Se = 78	Br = 80	
6	Rb = 85	Sr = 87	?Yt = 88	Zr = 90	Nb = 94	Mo = 96	— = 100	Ru = 104, Rh = 104, Pd = 106
7	Ag = 108	Cd = 112	In = 113	Sn = 118	Sb = 123	Te = 125	I = 127	
8	Cs = 133	Ba = 137	?Di = 138	?Ce = 140	—	—	—	— — —
9	—	—	—	—	—	—	—	
10	—	—	?Er = 178	?La = 180	Ta = 182	W = 184	—	Os = 195, Ir = 197, Pt = 198
11	Au = 199	Hg = 200	Tl = 204	Pb = 207	Bi = 208	—	—	
12	—	—	—	Th = 231	—	U = 240	—	—



From Robert H Baker,
An Introduction to Astronomy, © 1935 D. Van Nostrand Co.

Sunlight that is passed through a prism is broken up into a spectrum ranging from red to violet.

sociated professors at the University of Heidelberg — Gustav Kirchhoff (1824–87), a great clincher of experimental findings, and Robert Bunsen (1811–99), well known as the inventor of the Bunsen burner. They presented the following laws of spectrum analysis:

1. Any incandescent solid, liquid or gas *under high pressure* gives rise to a continuous spectrum [that is, it produces the band of rainbow colors, ranging from red to violet].

2. Any incandescent gas *under low pressure* gives a spectrum consisting of isolated bright-colored lines. [These lines serve to identify the gas in question.]

3. When light producing a continuous spectrum shines through a gas that is under low pressure, the spectrum will consist of a continuous band of color crossed by dark lines. These lines will occur at exactly the same places that the bright lines [mentioned in section 2] would have occupied if the intervening low pressure gas had been the only source of illumination. [Thus the dark Fraunhofer lines also serve to identify gases.]

Spectrum analysis led to the dramatic discovery of the element helium, not only upon the earth but also — and first — in the chromosphere of the sun. (The chromosphere is the ruddy gaseous layer surrounding the sun.) In 1868, during a solar eclipse, the spectroscope had been used to examine the chromosphere. Many bright lines were found, including a bright yellow line, which was at first assumed to indicate the presence of sodium. However, a French astronomer, Pierre-Jules-César Janssen (1824–1907), reached a different conclusion; he became convinced that the yellow line probably represented a new element. The British astronomers Edward Frankland (see page 1772) and Joseph Norman Lockyer (1836–1920) confirmed his belief; they demonstrated that the yellow line did not represent any element yet known on the earth. They proposed to call this new element helium (from the Greek word *helios:* "sun").

Until 1895 attempts to discover this solar element upon the earth proved futile. Then Sir William Ramsay (1852–1916), a British chemist, dissolved a radioactive mineral (Norwegian cleveite) in acid and studied the gas that resulted from this reaction. In the spectrum of this gas he found the yellow line indicating helium. It is not surprising that helium should have been found in a radioactive substance, since it is one of the stable end products of radioactive decay.

The story of the discovery and naming of other new elements from the time of Mendeleev to the present day is too long to tell here. As time went on, chemists came to agree that there were ninety-two chemical elements in all. It was felt that as soon as the missing elements in the periodical table were discovered, it would be complete for all time.

Chemists have now filled in all the gaps in the table. But even more surprising, they have added a number of new elements — all of them synthetic — to the ninety-two that had been supposed to represent the definite number. Since these man-made elements have atomic weights greater than that of uranium, they have been called transuranic (beyond-uranium) elements. The first to be discovered was neptunium; the second was plutonium, used in the manufacture of atomic bombs. Since then other artificial elements have been produced, and still others are in the offing. Truly, the periodic table of the elements has been filled to overflowing!

SCIENCE THROUGH THE AGES is continued on page 1925.

THE SUN THE LORD OF LIFE

The Mighty Power of our Ruling Star Dispensed Throughout Space by its Radiant Energy

WHAT WE THINK WE KNOW OF THE SUN

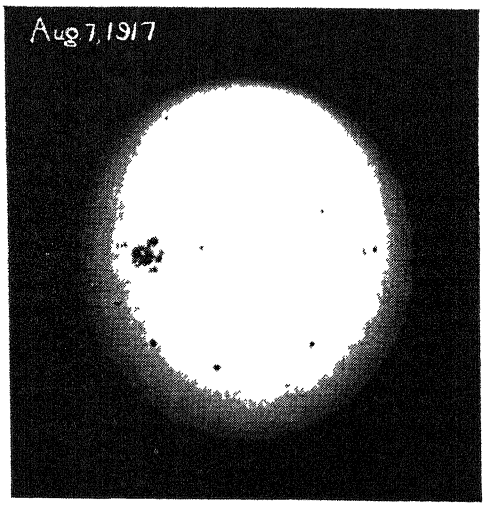
CERTAINLY astronomy has scarcely any record of greater achievement than the discovery that the sun is one of the stars. That discovery gives us a new conception of the universe. Further, the systematic comparison of the sun with the stars, notably as regards the quality of their light, teaches us far more fundamental facts about the universe than separate study of either could afford. We have everything to gain from the study of the sun as a star — as tnat particular specimen of the stars which is under our close observation, and from which we can learn, in large degree, what are the other stars, whose remoteness is so great. The sun is about ninety-three million miles from the earth, and the next nearest star, Proxima, is some twenty-six trillion miles away. Compared to any other star, the sun is under our immediate watchfulness. And the advances of spectroscopy, the analysis of light, are enabling us to classify the stars, and group the sun with certain others which conform to the particular type, and perhaps to the particular stage of evolution, which the sun exhibits. All this is the study of the sun with reference to the stars, and the new astronomy finds therein a most fertile and almost boundless field of inquiry.

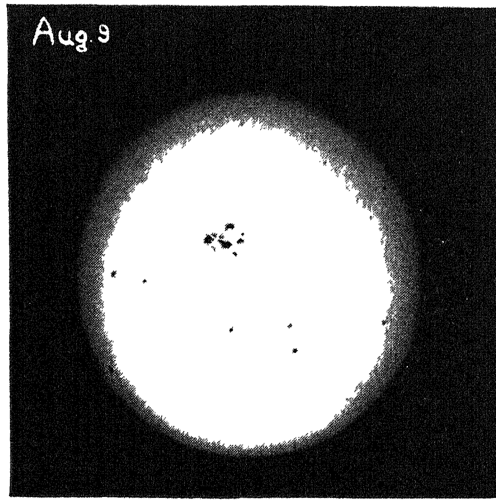
But, after all, the sun is *our* star, and we astronomers are human beings, born upon a satellite of the sun. Therefore the study of the sun in relation to our earth must certainly precede — in importance, as it also has done in the history of astronomy — the study of the sun in relation to the stars. We look at Sirius, or at the nebula in Andromeda, and they interest us intensely, and repay our study, but we cannot doubt that if Sirius, or any other individual star but one, or any nebula whatever, were at this instant to cease to be, the life of man would be wholly unaffected. They produce neither life nor death, health nor sickness; their movements and positions have no prophecies or warnings for the lives of men; their light suffices for us to see them by, and in some degree to study them by; it stimulates and illumines our minds but it scarcely serves to warm or illumine our bodies, nor does it in any way affect our earth as a habitation for us. Our interest in them is therefore almost wholly theoretical, detached, academic, impersonal, of today, and markedly contrasts with the feelings which animated certain of our forefathers who were devoted to astrology and who studied the stars in order to know what would happen to them or their credulous consultants tomorrow.

The star we call the sun, however, sustains our lives, causes death, drought, harvest, health and illness; its changes affect the magnetic needles of our compasses; and it would seem that the cycles of its spots and storms can be connected with climatic variations and even with fluctuations in the wheat supply and the growth of trees. Whatever the historical origin of the relation between the sun and ourselves, no matter whether it be our big brother, no matter whether our planet was originally captured by the sun, or was derived from a detached portion of the sun's exterior, it is certain that the existing relations between the sun and the earth are profound, numerous, indissoluble, and that they, beyond all other facts of the material world, condition the physical life of man.

We spoke in the previous paragraph about the numerous relations existing between the sun and our own planet, the earth. Let us see how we can justify that statement. The older astronomy centered its interest, inevitably, in the gravitational relation between the earth and the sun. Not many generations have passed since man discovered that the earth revolves around the sun; still fewer generations have passed since he discovered that this revolution is controlled by gravitation. That single fact can be and, indeed, has been extended so as to build up what has often been called a gravitational astronomy, and wherefore of the earth's orbit in its annual revolution around the sun. But after all, that is only the beginning of the problem. We must not forget that gravitation does not act between the sun as a whole and the earth as a whole. The law of gravitation asserts that every single particle of matter in the universe attracts every other particle with a certain force. The entire body of the sun, consequently, is pulling on every individual atom that composes the earth and vice versa.

It makes no difference of what materials the earth and the sun consist. Their gravitational action upon each other must, in





The photographs on these two pages show the rotation of the sun, as indicated by the passing of sunspots across the face of the sun's disc. The photographs were taken with a 12-inch telescope

in which the chief stress is laid upon the mutual attraction existing between the different heavenly bodies. There is no end to the investigations that this gravitational astronomy must pursue. If we are about to insist that, in a sense, that is only the beginning of the study of the relations between the sun and the earth, we must not underrate its importance. On the contrary, it is clear that the continued examination of the gravitational relations in this universe of ours is still fruitful and that it promises to be just as fruitful in the future.

Let us briefly set down here, then, just what this single gravitational relation involves. First of all, it explains the why a considerable number of details, be very different from that which astronomers have so generally assumed — namely, the action of two imaginary units pulling on each other at a certain distance and with a certain force. On the contrary, the sun and the earth attract each other's parts.

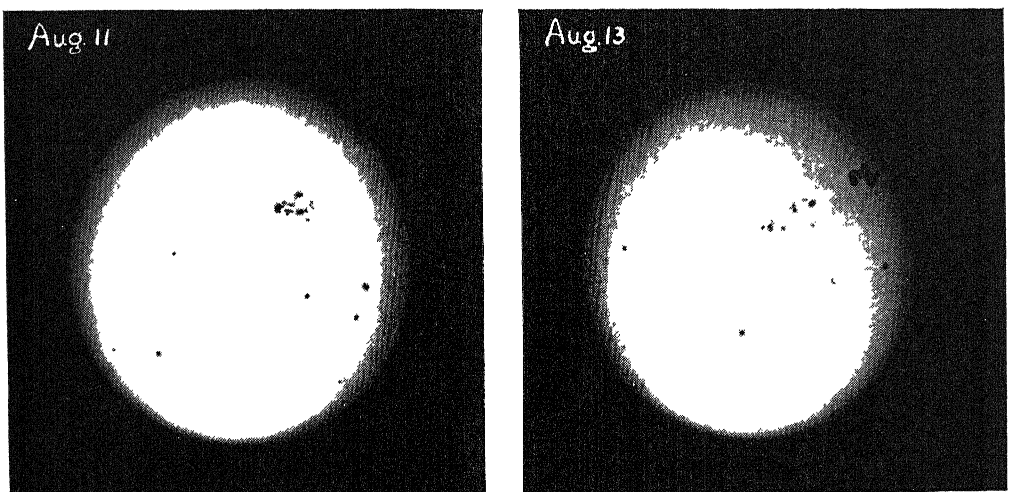
There is a classic example, of course, of this action of a given body, or bodies, upon a distinct part of another body. We know that the sun and moon, because they attract the earth, raise tides upon its oceans as it rotates about its axis. We know, likewise, that these tides, occurring as they do so often in the course of the years and the centuries, are bound to produce certain

effects upon the movement of the earth. We can assume, too, that these effects will become more and more noticeable in the course of the ages, as the earth continues to rotate.

As Galileo found when his telescope revealed the sunspots and their passage across the solar disc, the sun rotates upon its own axis just as the earth does and, as we know, in the same direction. (See Index, under Sunspots.) Because the sun is composed of gases, it rotates at different rates of speeds at different latitudes, unlike the earth, which, of course, is a solid body. At the equator the sun makes one rotation every twenty-five days. Its rotational speed increases with increase in latitude. Now as the sun turns on its axis, the gases of which it is composed are attracted by the earth.

Practically everybody knows that one body attracts another through the force of gravitation. It is by no means so universally known that gravitation is always and necessarily mutual. When an apple falls to the earth, the whole earth also rises to the apple. It is true that the attraction that the apple exerts upon the earth is exceedingly small; yet it is a definite attraction and it can be determined by examining the relative masses of the earth and the apple. In the same fashion, while the sun attracts the earth, it is no less true that the earth also attracts the sun. If the sun is rotating while under this constant gravitational attraction of the earth, it follows that successive portions of its surface will each in turn come nearer to the earth and will be more affected by its pull. As a direct result, tides of extremely insignificant proportions will be raised in the gaseous body of the sun.

"But," you may ask, "how can a tide be produced in the sun, which has no water of any kind, much less water so cool as to be liquid and form oceans." The answer is that it is only because we think in terms of accepted conventions that we assume that tides can be produced only in liquids. Tides depend upon gravitation and all matter is affected by this force. It is true that when liquid matter comes under tidal action, as in the oceans, we have liquid tides. But where gaseous matter is concerned, as in the atmosphere of the sun and in that of the earth, we have gaseous tides. Furthermore, it is now possible to demonstrate the existence of tides in the earth's crust raised by the sun and the moon — tides that astronomers were bound to expect long before they devised instruments that were delicate enough to detect them.



Yerkes Observatory

at Yerkes Observatory on August 7, 9, 11 and 13, 1917. Note that on the 7th the spots were at the extreme left of the sun's disc, while by the 13th they had reached the right edge of the disc.

Cities and continents raised and dropped several inches by attraction of the sun

Thus, every one of our great cities is ceaselessly being lifted bodily upwards, and then dropped again, a distance of several inches, by the gravitational action of the moon, and to a less degree by that of the sun, as the earth in its rotation brings the city under their respective attractions; the amount by which the earth is raised in any locality depends both on the latitude of the place and upon the position of the tide-raising body. The buried water-tube experiments conducted by Michelson have shown that our earth responds like a steel ball to the gravitational forces of the sun and moon. As a result of these forces, tides are raised on the surface of the earth and the cities in which we live are raised or lowered slightly. The maximum effect occurs when the sun and moon pull together. These tidal, rhythmical deformations of the crust of the earth must in due course affect the rotation of the earth and the destiny of the entire solar system itself.

We have alluded to gaseous tides, the atmospheric tides raised on the sun by the earth, and raised on the earth by the sun and the moon. Here is a subject which is practically new, and about which little can yet be said. But there can be no doubt that it must have a special bearing on some of the problems which meteorology has so long been trying in vain to solve. The questions of climate and weather do not here concern us, but we are bound to observe that the general gravitational influence of the sun upon the earth extends in such ways as these to the most intimate and seemingly local details of the immediate environment of man.

What would happen if, at any given instant, this invisible bond between sun and earth should cease to exist? Following Newton's first law of motion, the earth would immediately leave its elliptical orbit at a tangent according to what used to be called "centrifugal force," and would move further and further from the sun. It would cross the orbits of the outer planets, and, assuming that it escaped their influence, would soon pass into outer space.

Only as captives of the sun can we be free to live

The conditions of the earth's surface would change in just the opposite direction to that described by the great American astronomer, the late Professor Simon Newcomb, in a popular account of the approach of some imaginary star to the solar system, on its way to a collision with the sun. In that case the earth's surface would become hotter, with results soon fatal to mankind and to all forms of life. But if the gravitational bond between the earth and the sun were annulled, the earth, leaving the sun, would become steadily cooler, and the results would be just as disastrous. Marvelously adaptable as terrestrial life is to the conditions of the earth's surface, it could not survive any such changes as would follow if the earth left its orbit. This is the answer to the rather fanciful speculation put forward some years ago by Maeterlinck, that within a few centuries man might be able to control gravitation, and take his planet where he pleased. The best place for our planet is where it is, if we wish to survive upon it; and hence the force of gravitation which swings the earth in its orbit round the sun, conditions our existence. Only captive to the sun are we free to live.

We now know much concerning the effects of gravitation—how it holds the planets in their paths as they move around the sun, and how it holds man himself to his little planet Earth. But in spite of this, gravitation remains perhaps the greatest unsolved mystery of science. Although we know how it works, we do not yet know what it really is or why. It is to be hoped that some day, with more data constantly coming to light, we shall know more about its true nature. Already Newton's ideas of gravitation have been altered by Einstein's work. The sun is also a great magnet, and besides the powerful magnetic fields that develop in sun-spots, there is a permanent general magnetic field similar to that which surrounds the earth, so that the sun also has a north and a south magnetic pole distinct from the poles of rotation.

We see then that gravitation is not by any means the only force exerted by the sun, but that electric and magnetic forces play an important part in its influence upon the earth; if, moreover, radiant heat and light are also electromagnetic phenomena, as most scientists hold, then indeed the real meaning and potency of the sun is expressed in these two ways: the sun is a center of gravitational and of electrical force, in relation to the earth.

The sun as the great reservoir of the energy we use on earth

And so, if our description and understanding of the sun is to be abreast of modern scientific ideas, and is to make us prepared for future discoveries, such as the astronomers' "international attack upon the sun" will surely provide, we must accustom ourselves to "think electrically"—if a famous phrase may be adapted to the present purpose. The interesting facts of sun-spots, and the great solar prominences which shoot out hundreds of thousands of miles from the sun's surface, are helping us to understand the sun. Their beauty is undeniable, but what modern science cares about them for is the help they may afford in the task of unraveling the physics of the sun. For we are beginning to be able to sort things into their places, and putting those together which are really the same, and the result of the process is to teach that the sun really matters to us, and is interesting in itself, above all, because it produces almost all the energy we use on earth.

The sun the cause of many disturbances of magnetic nature

It has already been noted that changes in the condition of the sun affect magnetic conditions on the earth. The sunspots are vortices in the hot gaseous body of the sun, and are in the nature of electromagnetic disturbances. The tiny electromagnetic particles streaming out from the sunspots—some of them—impinge on the atmosphere of the earth, and cause not only the aurora but also magnetic disturbances which deflect the magnetic needle and upset communications systems. At this point the student discovers that he is compelled to turn aside, as it appears, to investigate the nature of light and heat, which seem to have nothing in particular to do with the study of the heavenly bodies. But the reader must not object. He is only being compelled to do what all the astronomers have been compelled to do before him. They have long studied the sun, in the ordinary astronomical ways, to ascertain its distance, size, etc., but within the last score of years they have all been compelled to turn to what is now called "solar physics" to make new instruments and build new observatories, like the great solar observatory at Mount Wilson, for the minute study of the light and heat of the sun, because to study them *here* is indeed the profoundest way of studying the sun *there!*

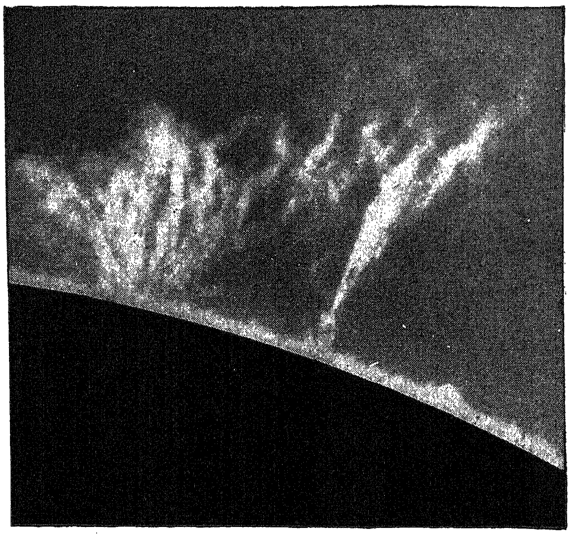
Electromagnetic waves pouring from the sun perceived as heat or light by us

In other words, the study of light and heat has come into astronomy, and has become as essential a part of it as has the study of gravitation itself. If all three turn out to be electrical facts of the universal ether, need we be surprised? What we now assert of the study of the sun is no less true of the study of the stars and, indeed, what is generally called the "new astronomy" depends entirely upon what we learn by studying the light and heat of the sun and the stars, in order to find out not *where* they are, which was the task, in the main, of the last generation, but *what* they are.

That vast center of radiant energy which we call the sun is continuously pouring into space, on all sides, a quantity of electromagnetic waves, as we may now name them for convenience, to which we have long given other names, according to the particular sense-organs by which we perceive them. If the retina of the eye is affected by any of these radiations we give them the name of light. If the nerves of heat in the skin are affected by any of these radiations we call them heat. If we have no senses which can be impressed by any of these radiations, we are unaware of their existence until special devices discover them — and then we hardly know what to call them.

The source of the heat and light which come to us from the sun has been indeed a great mystery and puzzle to astronomers. Various ideas and theories have been suggested at different times by students of the subject. Von Helmholtz was firmly convinced that the light and heat of the sun were the result of the sun's gradual contraction. It is true that contraction generates heat, but the difficulty with that theory was that it could not possibly account for the length of time we know the sun to have been shining. Today we are quite certain that the sun's energy is due to the transformations that take place in the atoms of sunstuff in the interior.

If all of the keys of a piano were struck simultaneously, a vast multitude of sound-waves, long and short, would be thrown through the air. That company of waves gives a very inadequate idea of the great gamut of waves, all electrical and fundamentally similar, which the sun is always sending into space. The comparison is inadequate for a very precise reason. Each key of the piano corresponds to a special string, which produces waves of a special length. The strings next above and below represent a certain gap or "musical interval" between waves of one size and waves of another. The piano cannot produce waves between those of, say, A and A sharp. But, of course, such waves exist, as we hear to our distress when a singer, trying to sing A sharp, sings something which is not A sharp nor yet A, but something between them. For the purposes of music these intervals must exist, and the piano and all other keyed musical instruments are made accordingly.



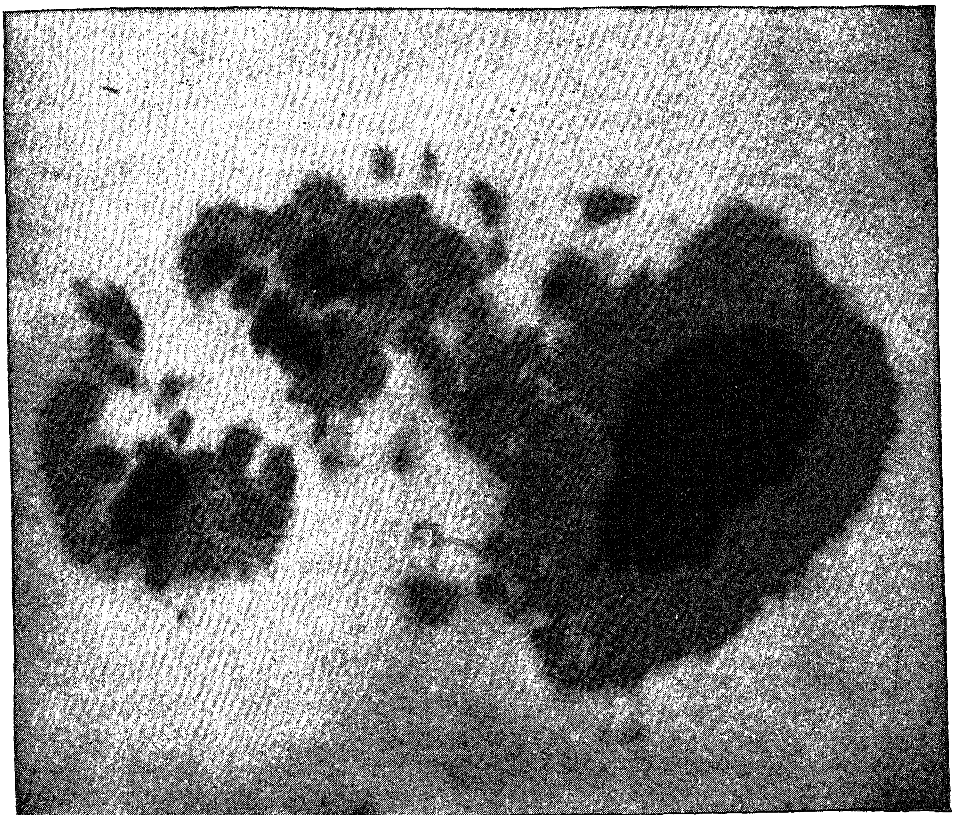
A SOLAR PROMINENCE 80,000 MILES HIGH
Mt. Wilson's spectroheliograph reveals an outburst of flaming hydrogen gas.

But the "full compass" of the sun's waves is full indeed, for it has *no intervals* at all. The waves it produces are of *all* intermediate lengths, by infinitesimal gradations, from the lowest note of its compass, as it were, up to the very highest; and the sun utters all these notes at once though there may be other notes outside of this range which the sun does not produce.

Astronomy and many other sciences would be in a vastly more advanced condition if the body of man were so made that it could somehow "sense" — one cannot say "see" or "feel" — the whole compass of the sun's vibrations, just as the ear can hear the whole of the compass of the piano. There are aërial vibrations below those which the ear can hear, and others above the highest we can hear. As for the compass of the sun's vibrations, we have two senses, vision and the thermal or heat sense, which we can, so to speak, join end to end, and between them they afford us direct knowledge of all of the sun's rays that men knew until a few years ago. But now we know that, even when the rays of radiant heat and the rather higher-pitched rays of light have been recognized as lying next each other in the compass of the sun, there reaches downwards a long range of radiations which are "cool" — that is, unfelt by our sense of heat; and upwards a long range of radiations which are "dark" — that is, unseen by our sense of vision.

We stand in the sun, and feel its heat and see its light. We cannot distinguish the notes, so to speak, of the sun's heat, yet the compass of solar radiations, all of which strike our nerves as heat, is really a long one,

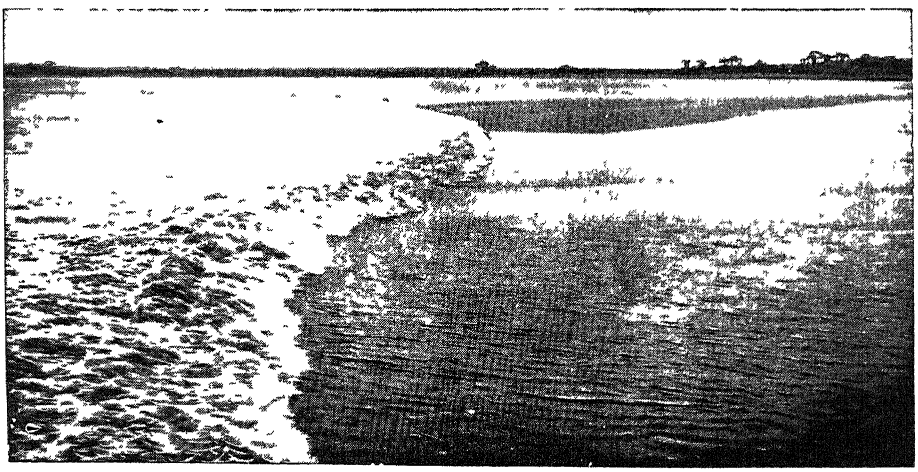
and some of the most important advances in solar physics are being made by the study of this dark but warm part of the spectrum, and of the part, lower still, towards the bass of the sun's mighty voice, which is not less dark, but is not even warm at all. The waves down here are usually called electrical, simply because they can be detected by electrical means and none other, but according to the modern theory they are neither more nor less electrical than the higher-pitched waves, of shorter wave-length, which our senses enable us to recognize as heat, and those, higher-pitched and shorter still, which we recognize as light. Beyond the upper limit of vision we can now recognize, by the mind's eye, interpreting the records of specially made instruments, a long series of "ultra-violet rays" which are of the utmost value to the astronomer, not only because of what they promise to teach us about the nature of the sun that issues them, but also because they powerfully affect many sensitive surfaces other than that of the retina of the eye, and so afford us photographs of the sun, and of the many other heavenly bodies which also produce rays of this particular type.



A SUN-SPOT, A FACTOR THAT MAY HELP IN UNRAVELING THE PHYSICS OF THE SUN
Photograph taken at the Greenwich Observatory, and reproduced by permission of the Astronomer Royal.

Just as the nerves of heat simply give us more or less of one undifferentiated sensation, so the eye gives us more or less of the "white light" of the sun when we stand in the daylight. But this white light really covers no less important a series of gradations, in the radiations which our eyes thus interpret, than the gradations in the series of heat rays. That is why the whole landscape of science has been illuminated, ever since, by a tiny ray of light which Newton admitted to his darkened room through a hole which he had cut in the shutter.

Exactly in front of the hole, in the path of the beam, he placed a prism, and on the opposite wall he saw a band of color, red at one end and violet at the other, which we call the "spectrum of sunlight". White light, then, is a chord of several notes — really an infinite number of notes — and the prism breaks the chord up into a band of colors, like an octave of keys upon a piano, because the rays are differently bent as they pass through the glass, according to their wave-length, and are thus thrown side by side, instead of being superposed, blended and indistinguishable, upon the screen which receives them.


THE TIDAL BORE AT MONCKTON, NEW BRUNSWICK

Extend and amplify that prism, provide specially suitable surfaces for the different parts of the spectrum to fall upon, place thermometers in the various parts of the beam, and in the dark areas, on either side, where the real beam extends, test the action of magnets upon the beam, compare the details of it with those of light from other sources, from a candle and a star and a glow-worm, and you are simply repeating and adding to the experiment of Newton, in the practical branch of science now called spectroscopy, or spectrum analysis, which may one day hang a murderer by detecting the changes produced by prussic acid in the color of blood, and the next day may tell us the chemistry of Sirius or the magnetic behavior of a sun-spot. Only a prism, through which you can see nothing clearly; yet through it man has seen further into space, deeper into the atoms of the sun or of his own blood, than all the telescopes and all the microscopes in the world had ever, and can ever, avail him.

It is this spectroscopic view of the sun which now dominates astronomers, and it is the physics and the chemistry of the sun that now engage their attention beyond everything else. These hold in them the key not only to the sun, but to the stars; not only to sun and stars, but to the history, and perhaps the destiny, of bodies no longer radiant, such as our own earth. We peer into the sun with a prism in order to see the hidden depths of the earth.

Impossibility of securing final accuracy in measuring and weighing the sun

But first, in a few paragraphs, we may rehearse the main telescopic facts of the sun, to which the work of the nineteenth century was so largely devoted. This is not to say that the work has been finally done. Every new estimate of the size, the mass, the distance of the sun will be different from the last, not merely because of individual errors of observation, which cannot be wholly obviated, but also because much depends upon the method employed, and because no degree of astronomical exactness is ever final.

These considerations deprive the "latest estimates", in astronomers' eyes, of any unique importance; astronomers know that these latest estimates will soon be superseded.

The scientific value of the various results depends not upon the results themselves, but upon the study and understanding and comparison of the particular methods employed. Let us therefore not pretend to be more accurate than we really can be, and let us aim especially at the one object that can be attained — which is to obtain sound general conceptions of the magnitudes which we are to consider.

The table given on page 4128 shows the comparative dimensions of the sun and the planets. To state a dimension in precise figures is simply to mislead, for the sun has a great gaseous envelope, of gradually diminishing density; and who shall say at what point the sun ceases or begins?

Comparisons that give an idea of sizes in the solar system

If we note that the diameter of the sun is somewhere about 864,000 miles, the reader must particularly beware of supposing, after examining the figures that we have given in the table mentioned above, that the sun has a surface like the surface of the earth — which, in any case, is not the surface of the earth but only the level at which the solid and the gaseous parts of the earth succeed each other. To determine the real surface of the earth we should have to ascertain where the atmosphere ends, about six hundred miles above us. The sun has no such solid surface, at any level of its substance, as the earth has.

The size or volume of the sun and its mass are, of course, two different things, which must never be confounded. So far as size, bulk or volume is concerned, we might cut up the sun into more than a million pieces, each of which would be larger than the earth. But the mass of the sun is not proportionately greater than the mass of the earth. By mass we mean, of course, the amount of matter in anything, and that is what we want to determine for the sun. We cannot speak of the sun's weight, be it noted, for weight is simply the result of gravitation; and if gravitation ceased, nothing would have any weight; but the mass, the amount of matter, in things would remain. Now, the matter composing anything may be lightly or loosely packed. Generally, the rule is that the matter of hot things is more loosely packed; heat expands them, and so we may expect the intensely hot sun to be, on the whole, much less dense than the earth.

That is indeed the case; and though the sun is more than a million times as large as the earth, it is only some three hundred thousand times as massive or "heavy". But though "heavy" conveys the idea, the word is dangerous to use, for it conveys the notion of weight, which depends on gravitation, which varies with distance, whereas the amount of matter in a thing is the same, of course, whether we study it near or from afar.

How the density of the material of which the sun is composed is estimated

What we call the "density" of any body expresses the relation between its volume and its mass — the smaller the volume into which its mass is packed, the greater is its density, and *vice versa*. In science, the density of water — under certain stated conditions of temperature and pressure — is adopted as a standard of comparison. Taking the density of water, then, as unity or one, we find that the earth as a whole (including, of course, its water) is about five and a half times as dense as water — or five and a half times as "heavy", in popular language, as a similar volume of water would be. But the density of the sun, as compared with that of water (1.00) and the earth (5.52) is only about 1.42, if, indeed, it is quite so much

Such a figure, of course, only represents the density of the sun as a whole — its mean density. But gravitation is at work between the particles of the sun, pulling them together, and hence the weight of the outer parts of the sun, or any other such body, presses upon its inner parts, and the density of the sun, as of the earth, must increase, steadily on the whole, from its surface to its center. The outer parts of the sun, consisting of rare hot gases, are, of course, far less dense than water, but the density of the interior of the sun, where the effects of the mutual gravitation of the particles composing its gigantic mass are fully displayed, must be enormous.

The unimaginable and uncalculated temperature existing at the sun's core

Indeed, astronomers and physicists find it very hard to imagine what the state of matter can be in the center of so huge and so hot a body as the sun, where a tremendous temperature is making for expansion and a tremendous pressure is making for compression, both such a temperature and such a pressure being far beyond anything which we can experimentally produce and study on our earth.

The temperature of the sun is no less interesting than its volume and its mass, but cannot be stated with the same definiteness. We know it must be very high, and Sir Arthur Eddington derived an internal temperature of about 20,000,000° C. and a surface energy output of two ergs per gram-second. The spectroscope has shown that the different levels in the substance of the sun vary in temperature, and it is supposed that violent local phenomena also change the temperature of the sun in various places from time to time. But the figure of 6000° centigrade, which is close to the best modern determinations, will suffice to show how hot the radiating surface of the sun must be; and the interior of the sun, as we have just remarked, is inconceivably hotter.

The sun too hot to burn — as chemical combinations of combustion impossible

But even the surface temperature of the sun is, at the least, so high that, first, none of the complicated compounds necessary for the development of living matter could exist in it; and, second, not even the simpler and more stable compounds, such as water, carbonic acid or sodium chloride (common salt), could exist in it. At the temperature of the sun even such compounds would be broken up into their elements. All the elements composing these compounds exist in the sun, as we shall learn later, but they exist uncombined, and the chemistry of the sun is almost exclusively a chemistry of elements, though not exactly elementary chemistry. We said "almost exclusively", for recent spectrum analysis indicates the presence of slight amount of some refractory oxides, such as titanium oxide, in the cooler portions of sun-spots

The amount of heat given out by the sun is a quite distinct measurement from that of the sun's temperature, and the study of it raises the further question as to its source. This is itself a matter which might be discussed in a large treatise, but we can already make one definite contribution to it from our knowledge already gained. If the sun is so hot that no compounds can exist in it, then the process of combustion, which produces heat in our furnaces on the earth, cannot occur in the sun, for combustion is the formation of compounds between oxygen and other elements, such as hydrogen and carbon. But water and carbonic acid, the respective products of such combustion, could not be formed at the temperature of the sun. We know definitely, then, even at this stage, that *the sun is not burning*. The source of the amazing output of radiant energy of the sun is not combustion, but appears to derive from atomic energy.

The figures of the sun's distance from the earth constantly revised

One other figure we may conclude this chapter by stating. How distant is the sun? That question, which astronomers have so long asked, needs restatement. The earth revolves round the sun in an elliptical orbit. Therefore what we should ask is what is the mean distance of the earth from the sun, its "average distance", in popular language. This is a figure which astronomers are constantly revising, but in round numbers the mean distance of the sun from the earth is 92,600,000 miles, the diameter of the sun is approximately 864,000 miles, and its mass is close to 330,000 times that of the earth.

One other figure requires to be added. The sun rotates upon its own axis. The earth's rotation occupies twenty-four hours, which we call a day. The sun's rotation occupies twenty-five such days, but the figure varies from the sun's equator to the poles and probably from the surface to the center, for the sun is not a solid but a gaseous body. Such, then, are the chief numerical facts of the "orb of day".

THE CONTENTS OF THE AIR

The Commingled Constituents of the Gas; Its Elasticity, Weight, Humidity, and Useful Dustiness

THE PLAYGROUND OF ELECTRICITY

WE have considered the air in general in its larger relationships to the world; let us now consider, more in detail, its physical and chemical aspects.

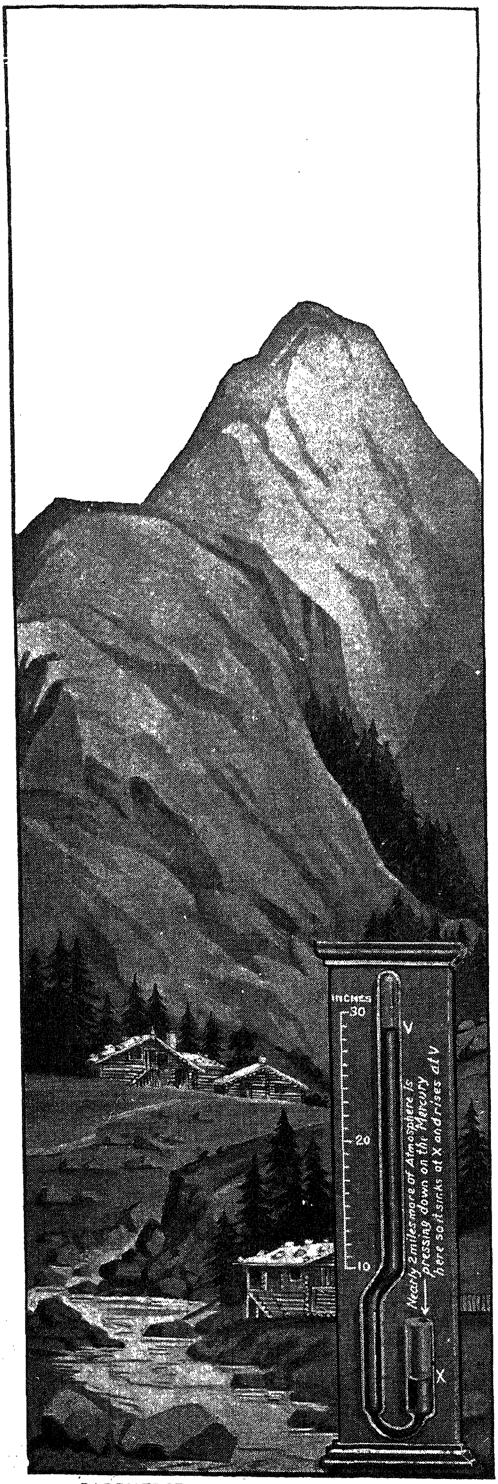
Air, as we have said, is gas, and, being so, it behaves as such: it is elastic, as every air-gun demonstrates; it presses equally in all directions, as our own bodies witness; it expands with heat and contracts with cold, as every pneumatic tire illustrates; and its volume at a constant temperature varies inversely with the pressure to which it is subjected.

Like all gases, it is very light; at sea-level a pint of dry air at a temperature of 60° F. weighs only ten grains. Yet, light as it is in small amounts, in the huge quantities in which it occurs in nature it exercises a considerable pressure. At sea-level the atmosphere exerts a pressure to the square inch of about $14\frac{3}{4}$ pounds, or approximately the weight of two gallons of water This seems light, considering that the column of air is about two hundred miles high, but when we take larger areas the figures are surprising. Thus, at sea-level, on a square foot the pressure is over 2000 pounds, and on an acre about 44,000 tons. The whole weight of the atmosphere is equal to a layer of mercury 30 inches high, or of water 34 feet high, spread over the whole surface (oceanic and continental) of the globe, and, according to the calculations of Sir John Herschel, amounts to $11\frac{2}{3}$ trillion tons, or $\frac{1}{1,200,000}$ of the weight of the earth. A man of ordinary build when at sea-level is exposed to a pressure of about 12 to 14 tons. Of course, if concentrated on a man's head or chest, this would be crushing, but it is exercised in all directions, up and down, from right and from left, from within and from without, and so it is hardly felt. It is this equality of pressure from within and from without that insures even the delicate film of a soap-bubble from bursting.

We have spoken of the air as having a certain weight and exercising a certain pressure *at sea-level,* but it must be clearly understood that both depend upon the enormous mass of superincumbent air. That below is pressed upon by that above, and thus becomes denser and heavier. If all the air were of the same density as that at sea-level, then a layer five miles high would suffice to account for the pressure we find there; but the air steadily diminishes in density as we ascend, and so the pressure there is due to a layer 200 miles or so high. At an elevation of 18,000 feet, the weight of a pint of air would have have shrunk to half, and the atmospheric pressure on a man on the top Mount Everest from 12 or 14 to 5 tons. On the other hand, in the valley of the Dead Sea, which is below sea-level, a man would be exposed to extra pressure.

The weight or pressure of the air is usually measured by a mercury barometer, the principle of which is as follows:

If a tube about 33 inches in length, closed at one end, be filled with mercury, and the open end inverted in a bowl of mercury, *all* the liquid in the tube will not run out into the bowl, provided the open end is kept below the surface. Some of it will remain, forming a column rising 30 inches above the surface of that in the bowl Now, mercury is a heavy liquid, and yet



BAROMETER AT BASE OF A MOUNTAIN

whatever the size of the tube, it remains at a height of 30 inches. If a similar experiment be made with water, it will be found to stand in the tube always about 34 feet.

What holds the liquids up? Undoubtedly it is the weight of the atmosphere resting on the surface of the bowl. It forces the liquids up the tubes just as the pressure of the gas in a bottle of soda water forces it up the central tube and out at the nozzle. If this be so, then if we ascend a hill so as to reduce the weight of the superincumbent air, the mercury ought to fall in the tube; and that is just what it does. In fact, the mercury is found to rise and fall as the weight of the atmosphere increases and decreases, and, by noting the height of the mercury, we can measure the pressure of the atmosphere. That is the principle of the familiar mercury barometer, or weather-glass.

In other barometers known as aneroid or dry barometers the mobile mercury is replaced by the elastic corrugated top of an air-tight metal box, partially exhausted to avoid heat movements. This elastic top falls and rises as the pressure of the atmosphere increases and decreases. The movements of the metal top are transmitted to a lever, and through this to a pen or pencil, which makes the record on a revolving cylinder for future reference.

At sea-level the height of the mercury column is about 30 inches; at 18,000 feet (since, as we have said, the pressure at that height is only half that at sea-level) only 15 inches. At 21 miles high the barometer would stand at half an inch.

In a general way, the barometer falls half an inch for each 900 feet of ascent, and thus altitudes can be roughly measured. But it must be remembered that when air is heated it expands, and thus becomes lighter per unit volume, quite apart from the matter of altitude. It must also be noted that water-vapor in the air diminishes the density of the air. Further, the average normal barometric pressure at sea-level varies in different parts of the globe. There is a zone of maximum pressure on the sea between latitudes 30° to 35°, and the pressure then declines gradually towards the poles.

HOW CLOUDS AND MISTS AFFECT THE CLEARNESS OF A LANDSCAPE

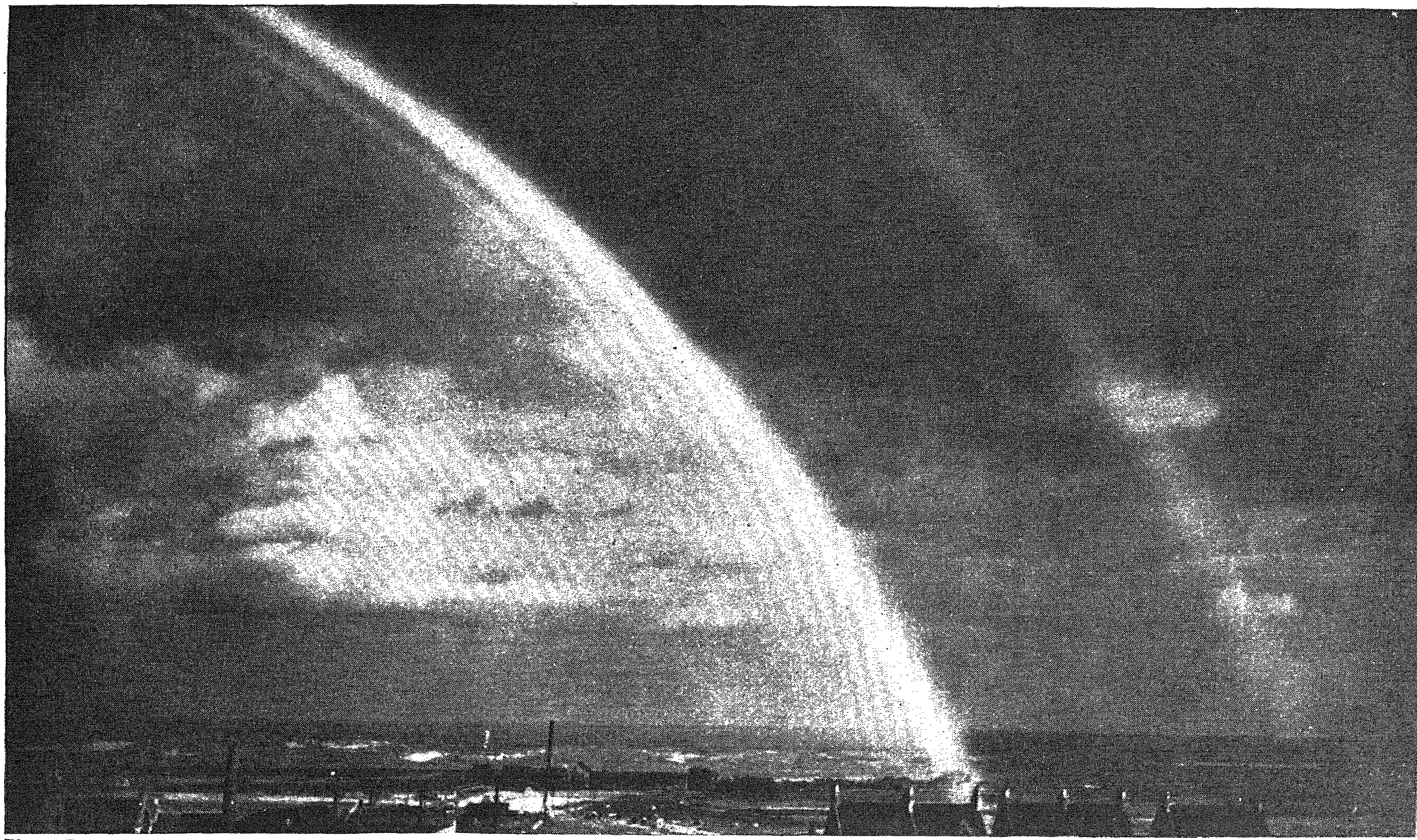


Photo: G. A. Clarke, U. S. Weather Bureau

Heavy or swelling cumulus and ragged low clouds of bad weather. The presence of a screen of rain falling in the middle distance is shown by the rainbows, primary and secondary.

We have spoken of the air as a collection of gases. What are the gases of which it consists, and where did they come from, and what do they do besides rushing about and exercising pressure?

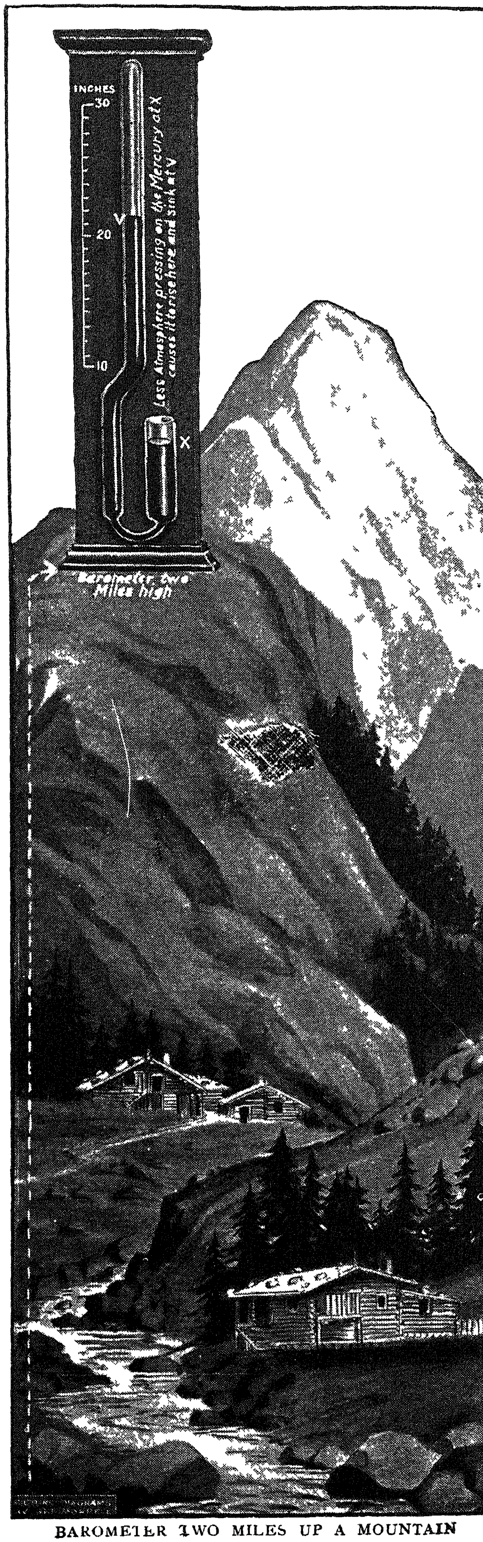
The chief gases in the atmosphere are oxygen, nitrogen, carbon dioxide, water-vapor and argon, and there are traces besides of helium, krypton, neon, xenon, hydrogen, hydrogen sulphide, nitric acid and ammonia The average volume composition of the gases in the atmosphere is given in the following table

Gases	Volumes Per Cent
Oxygen	21 00
Nitrogen	78 00
Carbon dioxide	.0 03
Argon	0.93
Water-vapor	Variable
Helium, krypton, neon, xenon, hydrogen, hydrogen sulphide, ammonia	Traces

The gases of the air are not chemically combined they make up only a mechanical mixture wherein the molecules of all the gases fly about freely and independently

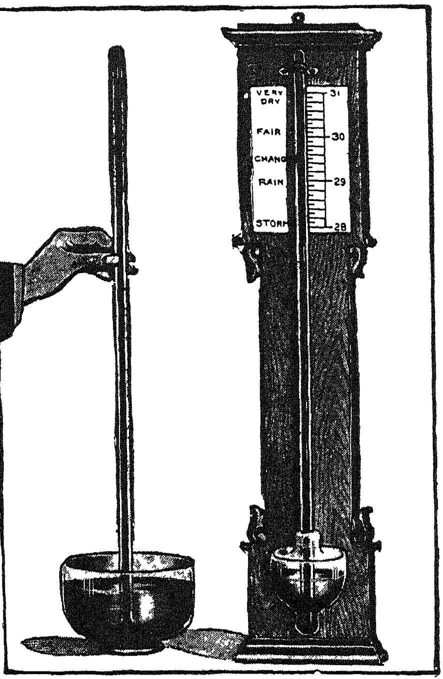
Let us look for a moment at the property of some of the gases.

The wonderful gas oxygen, the king of all gases, was first discovered by Scheele, a poor Swedish drug clerk in 1773 In 1774 Priestley obtained it by heating red oxide of mercury and collecting the gas given off. As his work was carried out without knowledge of Scheele's experiments and as he first published his results he is usually called the discoverer of oxygen He found that combustion took place better in it, and that mice lived better in it, and he came to the conclusion that it was very pure air — "between four and five times as good as common air" He inhaled it himself, and reported: "The feeling of it to my lungs was not sensibly different from that of common air, but I fancied that my breast felt peculiarly light and easy for some time afterwards." A few years later the French chemist Lavoisier made an analysis of the air, and showed the place of oxygen as one of its constituents. In this way modern chemistry began with the introduction of the analytical balance.



BAROMETER TWO MILES UP A MOUNTAIN

Oxygen is a colorless, odorless gas. Besides forming more than a fifth by weight of the atmosphere, it forms eight-ninths of all the water of the world, and more than half the crust of the earth. It plays the leading part in the vital function known as respiration, and on its chemical activity combustion depends. Sulphur, phosphorus, charcoal and even iron wire when well heated will burn vigorously in oxygen.



THE PRESSURE OF THE ATMOSPHERE APPLIED TO THE MERCURY BAROMETER

If a glass tube about thirty-three inches long is filled with mercury, and the lower end placed open in a bowl of mercury, that in the tube will run into the bowl until thirty inches remain in the former. Then it will stop It is held up in the tube by the pressure of the air on the surface of the mercury in the bowl If the air becomes lighter the mercury in the tube will sink; if it becomes heavier the mercury will be driven up higher. This is how the barometer works. The pressure of the atmosphere was discovered by the Italian Torricelli.

The proportion of oxygen in the atmosphere is wonderfully constant, and extreme limits would seem to be 21 to 20.6 per cent.

Ordinarily a molecule of oxygen consists of two atoms, but sometimes it occurs in a three-atom combination. In this triatomic form it is known as "ozone," which has a very strong odor and increased chemical activity. It is usually prepared by electrical discharges through the air, and by the oxidation of phosphorus. Owing to its great chemical activity it is a great purifier of the air, burning up all organic matter with which it comes in contact. Ozone, in nature, is formed by the action of the ultra violet rays of the sun on the oxygen of the air. As the lower dense air is not permeable to these rays, ozone is more abundant in the cold dry dust free upper air and is scarcely found at all in the dust laden city air.

Carbon dioxide was first distinguished from air by Van Helmont about 1620; in 1755 Black called it "gas sylvestre" and in 1785 showed it to be an oxide of carbon. It is colorless, odorless and half again as heavy as air. In the processes of combustion and respiration, carbon and oxygen unite and form this gas, and it is also given off in large amounts from the ground, specially in volcanic regions. At ordinary temperatures and pressures water takes into solution about its own volume of the gas; and the carbonic acid solution so formed has a somewhat corrosive action on the rocks of the crust of the earth.

It is from the carbon dioxide in the air that the green plants obtain their carbon; and since all animal life ultimately depends on vegetable food, carbon dioxide may be said to be the keystone in the arch of life; yet animals suffocate and lights refuse to burn if immersed in this gas. When carbon dioxide meets with lime it enters into combination with it, forming carbonate of calcium; and if lime-water be shaken up with air the clear liquid becomes whitish and opaque, owing to the formation of carbonate of calcium.

Likewise, if the breath be bubbled through lime-water, the carbon dioxide in the breath will form carbonate of calcium, and will render the clear fluid turbid. The carbon dioxide can be liberated again from the lime by treating the carbonate of calcium with an acid, such as vinegar; and if eggshell, or a piece of chalk, or a piece of marble, or carbonate of calcium in any other form, be treated with a suitable acid the carbon dioxide is liberated in a similar manner.

In open air the percentage of carbon dioxide hardly varies, but in closed rooms it often increases considerably, and the increase is usually considered a criterion of the impurity of air.

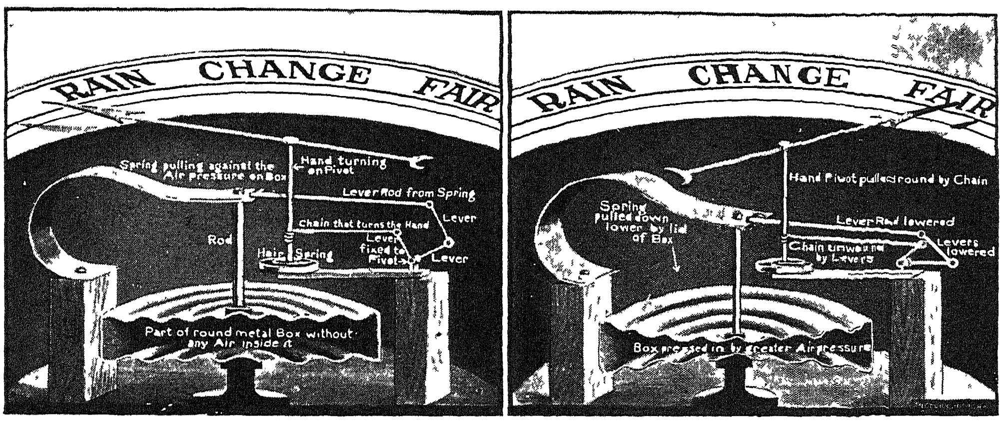
Nitrogen is a most negative gas: it has no color, no smell and no pronounced affinities. It simply dilutes the other gases of the air, and gives the atmosphere more weight, force and filtering capacity. It is, moreover, the original source of the nitrates in the soil, from which plants assimilate their nitrogen.

The gases of the atmosphere are always well mixed; and if any gas be formed in excess in any open locality it is quickly dispersed and lost in the general mass of the atmosphere. This is due to that movement of gases known as "diffusion", which causes them to intermingle automatically with each other until a perfect admixture is effected. Liquid also, even of different densities and arranged in separate layers in one vessel in order of density, the heaviest lowest, will in time if mutually soluble form a perfectly homogeneous mixture. Solids are also diffusible, but gases possess this property in an eminent degree.

Like all gases, those of the air can be converted by cold and pressure into liquid and solid. At a temperature of 318° F. below zero air becomes a liquid, and, at a still lower temperature, a solid.

Water is a liquid, but its liquid state is unstable. It evaporates at all temperatures; very rapidly at high temperatures, and less so at low temperatures: but even when frozen solid water still evaporates and changes from ice into vapor. There is therefore always some water vapor, or water in the gaseous form, mixed with the oxygen, nitrogen, carbon dioxide and other gases of the air. Water-vapor is lighter than oxygen and nitrogen. Thus at a temperature of 50° F. it is one-third lighter than air.

It is commonly imagined that the air sucks up the water, but that is a quite erroneous conception of evaporation. The air merely helps to warm the water, and to keep it warm, but even if there were no air above the seas and other bodies of water, still the vapor of water would rise. It is heat that agitates the molecules of liquid water, and that drives them into the air as molecules of gas that dash to and fro. The higher the temperature of the air, the greater the amount of water-vapor the atmosphere will contain.



PICTURE-DIAGRAM OF THE ANEROID BAROMETER AND PRINCIPLE ON WHICH IT WORKS

Thus, at 32° F. the air can hold 1–160th, at 59° F. 1–80th, and at 86° F., if saturated, it holds 1–40th of its weight of water-vapor. Roughly, for every increase of 27° F. the amount of water-vapor the air can hold in proportion to its weight is doubled. *Vice versa*, every fall of 27° F. halves the air's capacity for water-vapor, and, accordingly, any drop in temperature is liable to cause a deposition of water-vapor from the air in the form of mist, cloud, rain or dew. If the air at any temperature contain its full quantum of water-vapor — if it be saturated, that is to say — then a very light fall of temperature will suffice to reduce some of the vapor to a liquid state; but if the air be not saturated a considerable fall may take place without condensation of the vapor.

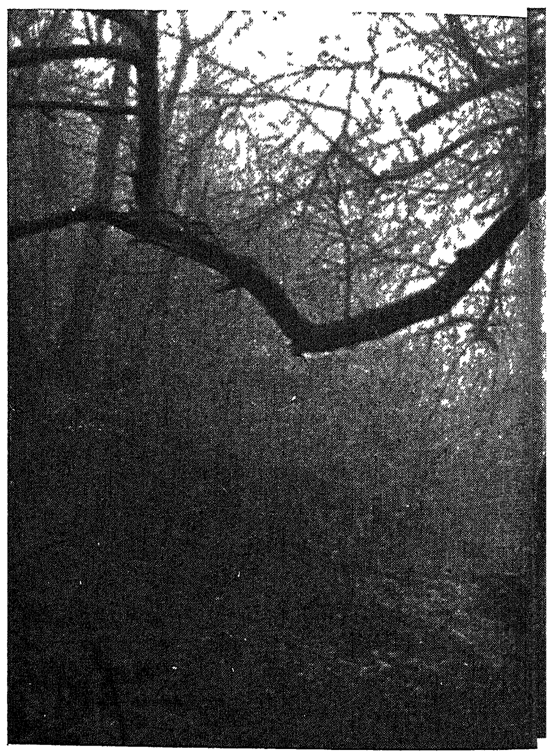
The amount of water-vapor in the air may be expressed either by its weight per unit volume (absolute humidity), or by the proportion it bears to saturation (relative humidity). Thus we may say that air contains 9 4 grams of water-vapor per cubic meter; or we may say that it has a "relative humidity" of 75 per cent—*i e*, it contains 75 per cent of the total water-vapor it is capable of holding

Meteorologists usually find the absolute and relative humidity of the air by a comparison of the readings of a wet and a dry bulb thermometer If we wrap a wet cloth round our head it cools our head; and likewise if we wrap wet muslin round a thermometer bulb (thus making it a wet-bulb thermometer) it cools the thermometer, but the cooling in both cases depends on the rapidity of evaporation, and this, again, depends on the relative and absolute humidity of the air; and if we know the difference between the wet and dry bulb reading, and also the barometric pressure, it is easy, with the aid of formulas or tables, to find the absolute and relative humidity.

The average relative humidity of the air in this country is about 66 per cent. As the air cools at night it becomes able to hold less and less water-vapor, and finally the layers near the ground may become saturated and any further lowering of temperature will cause a condensation of water-vapor in the form of dew. As the morning sun warms the air again, the relative humidity falls. In California the relative humidity may drop from 100 per cent at dawn to 22 per cent at noon. A hot wind may quickly lower the relative humidity 50 or 60 per cent. There may be as much as 80 per cent difference between the relative humidity of cool indoor and warm outside air under a tropical sun.

In dry, hot countries the relative humidity is very low. At Assouan on the Nile the mean relative humidity in the hours from 10 A.M. to 6 P.M. is 30.5. At Bloemfontein the annual mean relative humidity is 58 5. In the heart of the Libyan desert it may be as low as 9.

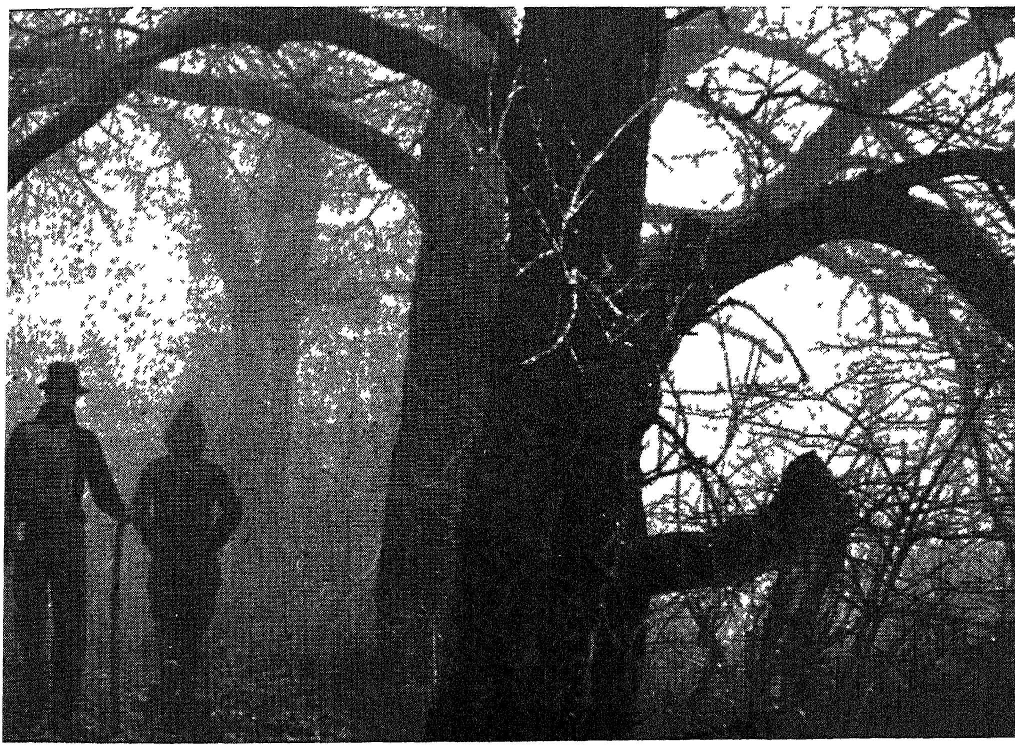
It has been customary to attach a good deal of importance to the relative humidity of the air; and meteorologists note the relative humidity as if the percentage figure had a precise and definite significance, but, as a matter of fact, relative humidity has very little meaning if considered by itself. We must always bear in mind that the higher the temperature, the more moisture the atmosphere can hold, the lower the temperature, the less it can hold. Therefore, a relative humidity of 60 per cent at freezing-point has a very different meaning from a relative humidity of 60 per cent at higher temperatures, for when the air is cold and the relative humidity is 60 per cent, a slight addition of vapor will cause saturation, while when the air is hot and the relative humidity is 60 per cent, much more water-vapor can be added before the saturation point is reached.



MIST IN THE WOODS. WHEN WATER VAPOR CON-

The absolute humidity of air—*i.e.*, the actual amount of water-vapor in it—is of importance, in that water-vapor contains latent heat, and, as clouds, reflects back the radiant heat of the earth.

The higher we ascend, the rarer and colder does the air become, and therefore the less water-vapor does it contain. Half the total water-vapor of the atmosphere is below 6500 feet, and three-quarters below 13,000 feet, while at 29,000 feet, the height of Mount Everest, there is hardly any water-vapor in the air at all. Not only is high air dry air, but, owing to its rarity, it is very *drying* air, and at high altitudes we find that dead animals dry up and mummify without decaying



U S Weather Bureau

DENSES IN THE ATMOSPHERE, IT MAY FORM EITHER RAIN, OR CLOUDS OR, AS HERE, MIST

When water-vapor condenses in the atmosphere, it may form either rain or clouds or mist. When it condenses on cold objects near the ground, it is called dew.

The other gases of the atmosphere — argon, helium, neon, krypton and xenon — are inert and occur in small quantities.

Besides gases, however, the air contains dust, germs and radioactive matter.

All small particles of matter suspended in the atmosphere, whether grains of salt, or grains of sand, or organic débris, must be considered dust, and dust particles of some kind or other are found everywhere in the lower atmosphere. The winds steal dust from the crust of the earth, from fields and deserts. The ocean breezes snatch salt from the ocean spray.

The volcanoes shoot dust high into the heavens. The furnace chimneys soil the sky with their carbon soot. It is surprising, too, to find how far dust can be conveyed The sun has been darkened in Teneriffe by clouds of dust borne across the sea from the desert of the African mainland. Red dust from China has been found in California, and fragments of microscopic animals have been found in the air of Portugal which must have been carried right across the Atlantic from America. The smoke of burning Chicago reached as far as the Pacific Coast, and African microorganisms have been detected in the air of Berlin. The eruption of Mont Pelée strewed dust on Barbados, 100 miles off, to such a depth that the weight of it was several tons to the acre.

Dust is also added to the atmosphere by meteorites. Every twenty-four hours from ten to twenty million meteorites visible as shooting-stars, and many more too small to be seen, invade our atmosphere; and meteoric dust can be found both in the air and in the silt at the bottom of the sea, though its fall there may not be recent.

Insignificant as dust may seem, it is yet of great importance to the world. In ordinary quantities, as we have seen, it is the main cause of the blue color of the sky; while the coarser, thicker dusts produce variegated and splendid color effects The gorgeous sunsets produced by volcano dust are well known, and the course of the dust round the world can be traced by the clouds of glory that accompany it on its journey. And the function of dust is more than artistic. Ordinary everyday dust it is that gives sunlight by day its soft and diffuse character, by catching and reflecting the sun s rays. Except for the dust, as we have said, we should see the sun and the stars in a black sky; the surface of the earth would shine, but it would shine as a glow-worm in the dark. Light passing through a dustless dark box is unseen, and only if dust be added to the air does the air become sunlit

The soft, shimmering light of twilight is produced by dust in the upper layers of air reflecting the light of the sun after sunset — that is, after the sun has set below our horizon. Dust colors the sky and lights the sky, then; but, paradoxical as it may seem, dust also darkens the sky, for dust is the scaffolding of clouds and mists and fogs Dust, the lightener, darkens; dust, the dry, makes the rain-clouds Water-vapor is itself invisible; it is only when it condenses as minute drops of water that it forms clouds and mists and fogs; but, without something to condense upon the water-vapor cannot condense, and the dust provides cold condensing surfaces. The presence of ions or electrified particles of gas in the air would also serve to cause condensation; but the quantity of ionized air is so slight that without the dust in the air we should have practically no mist, no clouds, no fog. The air would become supersaturated; and, if there were no particles in the air for the vapor to condense upon, every object on the earth's surface would become a condenser. Every blade of grass and branch of tree would drip with moisture; our clothes would become soaking wet; our houses damp, and the walls and every object in the room wringing wet.

TWILIGHT'S GLOW, SOFT AND SHIMMERING BY REASON OF DUST IN THE UPPER AIR

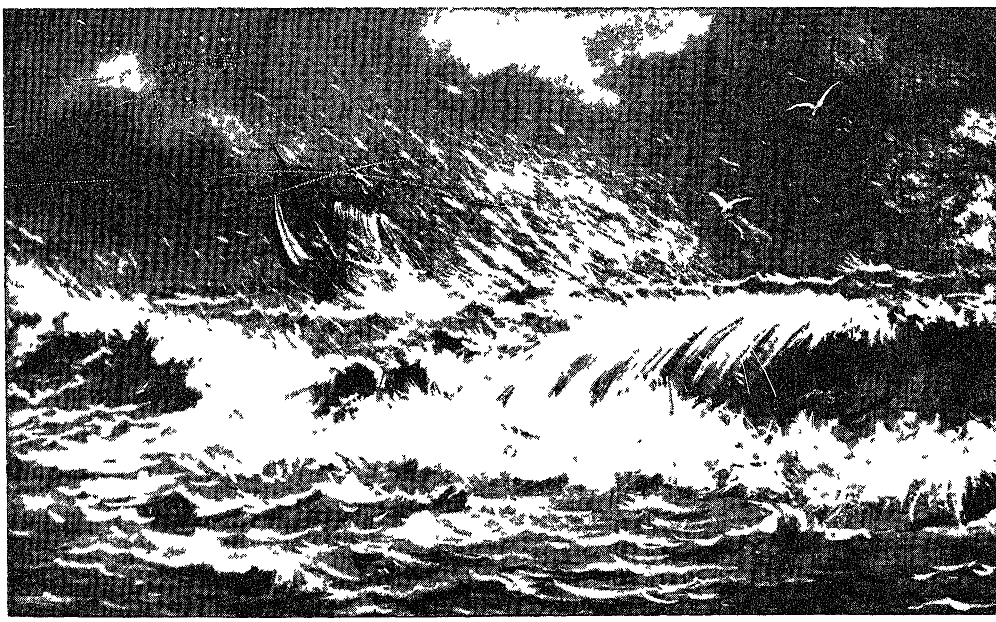
Whether the water-vapor condenses as cloud, or mist, or fog, depends on the quantity of dust present — the scantier the dust, the coarser will be the condensation.

The amount of dust in the atmosphere varies with the altitude, direction of the wind, locality and many other circumstances. As a rule, the air is most laden with dust in large cities, and indoor air is dustier than outdoor air. The amount is usually stated as so many particles per cubic centimeter. On the top of the Rigi mountain, in Switzerland, 420 to 12,000 particles per cubic centimeter were found; and over the Pacific Ocean, 280 to 2125 per cubic centimeter. In London outside air the number of particles found runs as high as 80,000 to 116,000 per cubic centimeter; while in a laboratory 1,860,000 particles per cubic centimeter, or 30,318,000 in a cubic inch, were counted. Smoking-rooms contain even more, since every puff from a cigarette contains, it is calculated, about 4,000,000 particles of dust.

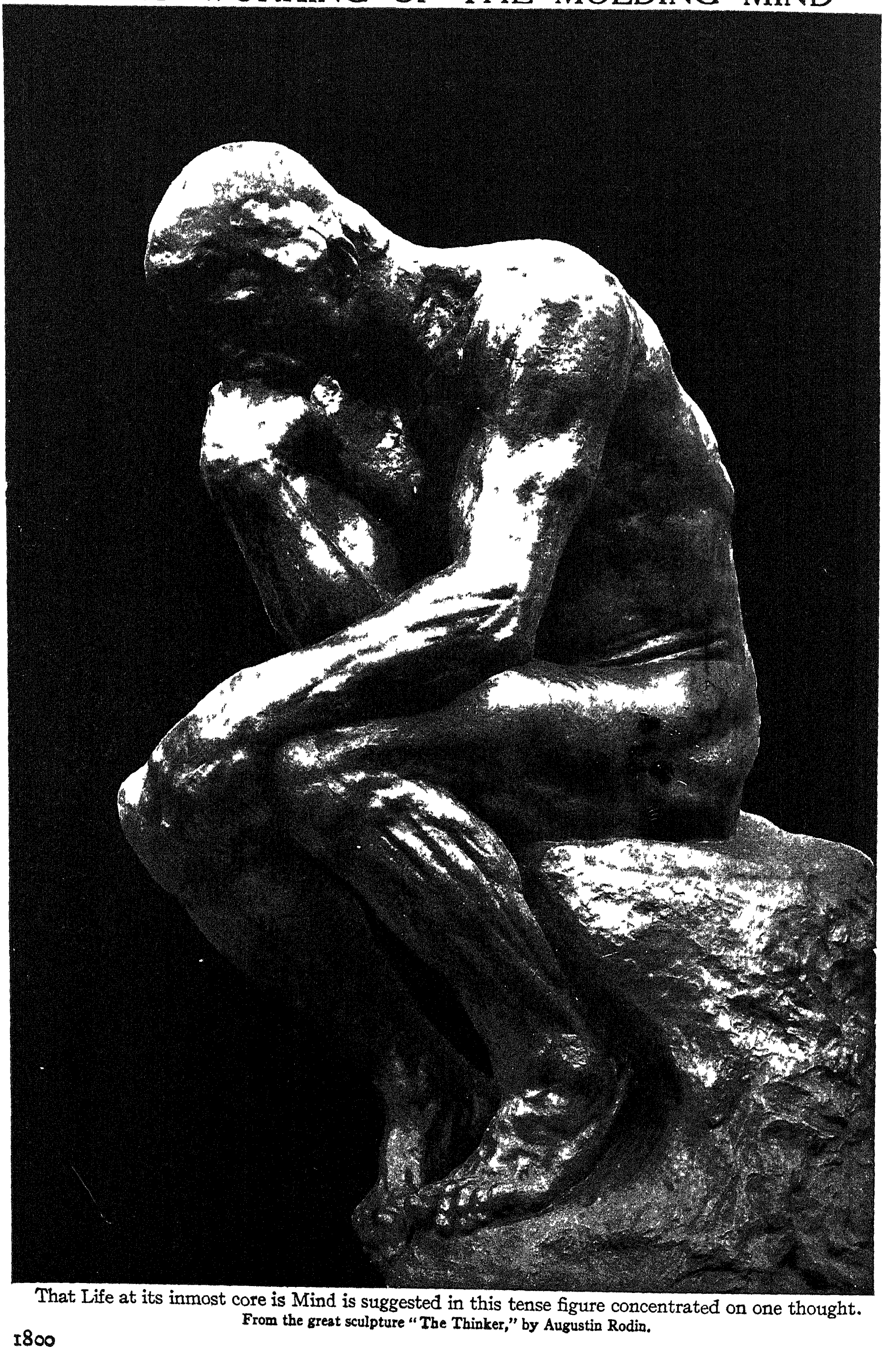
Germs must be considered along with dust, for they are just a special kind of dust. The ubiquity of germs is most surprising. Every sugary liquid left uncovered is soon invaded by yeast-cells and other fermenting organisms, and all dead organic matter is soon attacked by the microbes of putrefaction. But still germs are by no means so ubiquitous as lifeless, inorganic dust.

Tyndall exposed a thousand culture tubes to the air of London, and found that every one was invaded by germs. On the other hand, no germs invaded twenty-seven tubes open to air on the Aletsch Glacier (8000 feet). Indoors, in dark, dirty rooms, germs abound, and in a gram of dust from a room in Paris no less then 2,100,000 germs of various kinds were found.

It is a well-known fact that the atmosphere is charged with electricity, as shown by the electrical phenomena accompanying a thunderstorm. But the air is always charged with electricity, even in calm weather, and there is always a certain amount of electrical tension between earth and atmosphere. The tension is highest in winter, and lowest in summer, and is especially increased by the condensation of vapor. Generally the upper strata of the air are charged with negative electricity, just as the surface of the earth, while the intervening layer of air is charged with positive electricity. The electrical tension is so great in clouds that lightning will sometimes leap across between clouds as much as ten miles apart.



HOW SALT FROM THE SEA-SPRAY IS CAUGHT UP BY THE WIND



That Life at its inmost core is Mind is suggested in this tense figure concentrated on one thought.
From the great sculpture "The Thinker," by Augustin Rodin.

ONENESS OF LIFE AND MIND

Mind the Underlying Motive-Force of the Living World Aiming to Transcend Itself

LOVE AND INTELLIGENCE HAND IN HAND

NO theory of evolution can be called anything but a makeshift that does not offer us a positive explanation of the greatest triumph of evolution. That is the intellectual and moral nature of man. Though natural selection, mercilessly destroying incapacity to live, has had to be reckoned with at every stage in this process, we see clearly that it has not constructed either intelligence or love, though it may have first tolerated and later confirmed them. We require something more, if we are to bring the characteristic facts of man into the evolutionary scheme at all. So beggarly has always been the merely mechanical and negative theory of natural selection to explain the evolution of man's higher nature that, from the first, Dr. Alfred Russel Wallace, the co-discoverer with Darwin of the principle of selection, has always denied that this principle would account for these greatest triumphs of evolution. He has invoked a non-scientific, supernatural explanation for the origin ot the *psyche* of man; and though we cannot accept that explanation here, and do not find it necessary or desirable, we should note that one of the original discoverers of natural selection has always proclaimed its hopeless inadequacy to explain the greatest facts of evolution.

Those greatest facts are clearly two, though they are two in one, and we shall consider them separately in the light of the long foregoing discussion, which has given us the successive contributions to the theory of evolution, from Lamarck, at the beginning of the nineteenth century, to Bergson, at the beginning of the twentieth. The two supreme products of evolution for which we have to account are intelligence and love

These products we see in their highest form in man, and our explanation must include man. But, after all, we are evolutionists; we have studied the world of life in general, and we see clear evidence of intelligence and of love among the lower animals. Man is doubtless unique and unparalleled, but his characteristics, though so great, are not *new* in the history of life, and do not require us, all of a sudden, to abandon any theory which will carry us as far as from, say, the amœba to the ape.

We have already seen that the line of intelligence is one of the three great lines along which life has evolved. It has become most evident with the evolution of the particular type of nervous system which is characteristic of vertebrates, and which has been rising in complexity and in actual bulk from the earliest fishes up to man. The older materialist theory of evolution teaches that intelligence, and even consciousness, of which intelligence is an aspect, appears with the appearance of the brain, and as a consequence of it. Random variations in the protoplasm of germ-cells, controlled by natural selection, make the brain; and when this structure has been formed, consciousness and intelligence begin to appear

However, we know consciousness and intelligence, in a primitive form, are older than the nervous system of man, older than the nervous system of the fish, older even than any nervous system. They are part of the original nature of Life. They can be found in the lowest living organisms; and their appearance at their height in man is a progressive and purposive consequence of their inexhaustible "thrust," from the beginning of life at all.

Evidently animal psychology, popularly supposed to be the somewhat imaginative hobby of leisurely and elderly gentlemen, becomes a matter of life and death to the evolutionist who has come so far. Evidence of anything that can be called intelligence, in dog or cat or bird, is not merely a curiosity or a tale for an idle moment, but a fact for which science and philosophy are breathlessly waiting. We are not going to argue the point here. Overwhelming evidence of animal intelligence has already been presented in the section devoted to animal life, and that fact is a definite *datum* for evolution to interpret. It exalts the animal world, without in any degree debasing man, except for those strange people who cannot realize the idea of absolute worth, and only count honor or capacity worthy by contrast with lesser things.

Evidence of mind to be found in the lowest forms of life

But the proof of intelligence in ape or cat or dog does not suffice, for all of these are high in the rank of vertebrates, and possess a definite and complicated brain. The materialist theory, according to which consciousness is only a kind of phosphorescence that spreads around a brain of a certain stage of development, may still be arguable from the dog as from man. It is necessary for us to look very closely at the lowest forms of life, or, at any rate, at forms in which no nervous system whatever, let alone a brain, is to be found. Of course, intelligence and consciousness of any kind will need more looking for here, and will escape casual observation, for we cannot expect them to appear so saliently as when they have fashioned, or Life has fashioned, the special structure through which they appear so well; but the evidence is to be had, and its importance for science and philosophy can obviously not be overestimated.

We can afford to go as low even as the amœba and the humblest infusoria. Of course, they obey physico-chemical laws. So does man, and the fact is nothing to the point. But when we examine them closely, we find it impossible to explain their movements by reference to physico-chemical terms alone.

The existence of feeling and response in the humblest forms of life

The casual observer is content with such an explanation, but the various men of science who have really devoted themselves to this study, from Maupas, in 1883, to Jennings, in the last few years, have clearly proved that in these humblest manifestations of life there is evident "an effective psychological activity".

These creatures exhibit "behavior". They feel and respond — a notable fact in itself — so long as they are alive, but they do more: they learn, and choose, and refuse, and adapt themselves. We have already seen that life has taken a different course in the vegetable world, but it is to be remembered that the humblest plants exhibit these psychological traits also, and that in higher forms there is clear evidence of something psychical, even though it be imprisoned in its wall of cellulose. Lord Morley has referred to Wordsworth's famous declaration of his faith that "every flower enjoys the air it breathes" as a "charming poetic fancy and no more, and it is idle to pretend to see in it the foundation of a system of philosophy". We are not so sure today that Wordsworth did not express, doubtless with poetic license, a truth which *is* essential to our system of philosophy. But this is not the place in which to do more than simply state the existence of evidence suggestive of psychical traits appearing in the vegetable world.

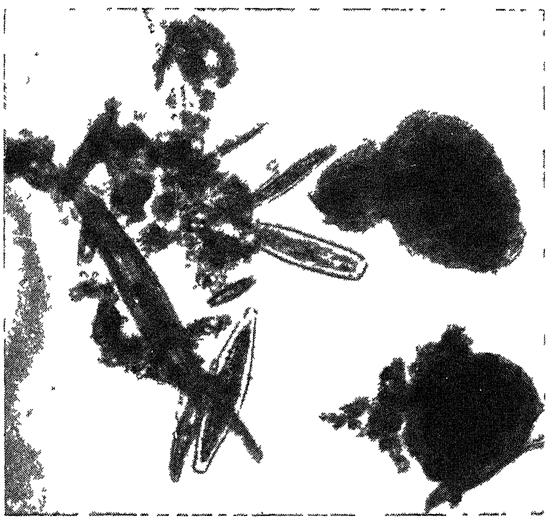
Life and mind are one through the whole scale of being

With that statement the argument is complete that mind and life are fundamentally co-extensive. Where there is life there is mind; and the phenomena of mind, at their highest and rarest, are natural and vital, and are evolutionally connected with and continuous with the facts of life in its humblest forms.

These — need it be insisted? — are tremendous statements, alike for science and philosophy, and are a subject for volumes. Our present concern with them is their bearing on our theory of evolution. The proposition that life and mind are really one:

that the function we call mind precedes and creates for itself the structure we call body, including the nervous system and the brain, even of man, is the *only proposition* on which we can base a theory of evolution that is worth a glance. The evidence for it has here been summarily stated; and the reader who would inquire into it further must consult Bergson's "Creative Evolution", and Dr. McDougall's remarkable newer volume on "Body and Mind". Here let us realize how valuable the perception of this truth is, and we cannot do so better than by looking at the alternatives.

One, already alluded to, is that, in short, of "drawing the line" at man. Thinkers of this school can accept the idea of evolution in plants without reserve, and they can accept it in animals as far as man. When they come to man they feel bound to distinguish. As regards his body, they have no doubt. His relation to the bodies of animals is duly discussed elsewhere in this work at considerable length, and is so evident that they do not gainsay it. They may not have, none of us may have, an adequate theory of the manner in which evolution occurs, but that does not matter; the theory that would take us as far as the ape will certainly take us as far as the body of man.


A PAIR OF AMŒBÆ ATTACKING DIATOMS
Amœbæ have free motion in water, the lower amœba is seen to have enveloped several diatoms in its substance. This picture is magnified 20,000 times

But these thinkers cannot accept the view that the *psyche* of man is also an evolutionary product. When mind becomes so glorious, it seems wholly separate and original to them, and they feel compelled to say that this highest part of man is a "special creation". The difficulty of this view is extreme if we remember that the thinkers who hold to this theory recognize the relation between mind and brain, and gc so far as to admit the brain to be an evolutionary product.

This, in other words, is to call the function a special creation, and the structure a product of evolution. Such a doctrine is plainly desperate, derived from the feeling that science must be abandoned, and logic, too, when we reach this point But that would be a lamentable conclusion if it were true, and to accept it would be to abandon science and discredit it, not only here but everywhere. The truth that mind and life are one, and have thus evolved together, delivers us from this *impasse*.

No less does it deliver us from the violent contradiction of our own creed which is evolved in asserting that evolution goes on and on, unrolling new and more complicated forms of one thing, living matter, until, all of a sudden, there appears a staggering novelty, with no history, called the intelligence of man. The evolutionist cannot deny or discredit that intelligence, for that is to discredit his own theory. And if he says that it suddenly comes without a history, he is also denying his own theory that evolution is universal, and that there are no exceptions to it. Thus the evolutionist, of all men, requires to see the truth that mind and life are really one, for that doctrine alone will enable him to make and complete a statement of evolution at all. Without it he must leave out the *psyche* of man; and who would care a rap for his theory then?

All this is great gain; inestimable gain, if we recall what we were asked to believe, by representative evolutionists, in the nineteenth century. It allows us to assert, without the monstrous self-contradiction of materialistic evolution, that the *psyche* of man is an evolutionary product.

The study of life is, in the final analysis, the study of mind

It makes evolution infinitely more glorious and important than if it were merely the evolution of bodies. It raises incalculably the study of the behavior of animals and plants, of every grade and in all possible circumstances, and it exalts biology, or the study of life, as mind alone can exalt anything. In the Universe, said Sir William Hamilton, there is nothing great but man, and in man there is nothing great but mind. We feel compelled to agree, whoever we be; but now we see that the study of life, even in its rudiments, and even in its mere physical mechanism, *is* the study of mind, which becomes at last, and which illuminates beyond words, the study of the mind of man.

But this transcendent gain of ours, as compared with the generation of evolutionists before us, involves also a loss, if to lose the worthless is loss. For, once we have grasped the relation of mind to life, once we have realized what evolution therefore asserts — which is the evolution of the minds of Shakespeare and Socrates and Newton from the feeble intelligence of some far-distant ancestor — we find that we have lost our comfortable assurance that we had an efficient theory of evolution. The automatic process whereby forms which cannot survive do not survive, which we call "natural selection", and which, even ten years ago, was thought to be "an efficient cause of evolution", is seen in the full measure of its irrelevance and inadequacy. There have been many bad dramatists, before and since Shakespeare. Their dramas are dead, and his alive. This is natural selection in a typical form. And we have hitherto talked of evolution at large as if this natural rejection of bad dramas had written "Hamlet"!

How Mind is the underlying motive force of the life of the world

Certainly we have lost what was not worth losing, and now we realize that we are very much in need. We still have to explain, even only to name, the motive force of evolution, but, once our need is known, it can be met. The motive force of evolution is psychical. It is the impetus of Life-that-will-not-be-denied, which "sweeps through the dull, dense world", and which we feel and exhibit and know at first-hand in ourselves whenever we really are ourselves. This is to assert that, in our century, we are compelled to state the theory of evolution in terms of mind instead of matter, and that the very theory which was supposed to be, and was stated as if it were, materialistic becomes the best warrant for the great doctrine, held by the supreme thinkers of all ages, that Mind is the underlying and motive force of the living world.

The original psychical impetus of Life expresses itself, we have already seen, in various evolutionary forms, of which intelligence is one. Here we need say no more of it in itself, but must pass on to note its historical relation to the other great triumph of evolution, which is love, the essential constituent of the moral nature of man and, in humbler yet often noble forms, of many of the lower animals.

Why Mind has been excluded as a section from this work

But before we observe the peculiarly dependent character of intelligence, let it be noted how the foregoing argument justifies, from the standpoint of science, the omission of any section called Mind from this work. The critical reader will observe that nowhere in these pages has mind been denied or dismissed as an unreality or as outside the scope of science; nor could anyone deny that there exists already a great science of the mind, called psychology. It has been formally laid down in the section on the Universe — a term which should surely include everything — that Mind is at least one of the ultimate realities of the Universe, and yet no attempt has been made to deal with it there, and it was even pointed out that in studying, for instance, the behavior of the heavenly bodies we must deny any interference with them by Mind, and must exclude Mind from those pages. Yet we have no section on this great theme. The reason will now be apparent. Mind and life are not things apart, much less are mind and man, the highest form of life, things apart.

Only by the evolution of love is the evolution of intelligence possible

The subject of Mind needs no special section, because the sections Life and Man are bound up with it, because life is ultimately psychical, and because no discussion of man could be other than dishonoring to the subject and the writer which did not regard his mind as the essential part of him — a proposition which now sounds all the juster when we have learned that Mind is, after all, the essential and all-important part of all life.

The special problem now before us is the evolution of the intellect; and the proposition which we shall lay down is that the evolution of intelligence, culminating in its highest form, the intellect of man, necessarily and absolutely depends upon the simultaneous, or rather the prior, evolution of love. These two, then, which we have called the triumphs of evolution, and which reach their highest in the mental and moral nature of man, are to be proved interdependent, and their association not an accident, still less a misfortune, but rather a necessity.

The sum of the matter, then, is that only by the evolution of love is the evolution of intelligence possible; and this statement must be weighed against that theory of evolution, unjustifiably based upon Darwin's theory of natural selection, which asserts that evolution depends upon a brutal struggle in which charity, sympathy, mercy, forbearance, pity are weakness, and lead to degeneration. This abominable theory, for which Nietzsche is chiefly responsible and which, since the death of Sir Francis Galton, has been renewed by certain advocates of eugenics who wish to humanize man by brutalizing him, is the direct opposite of the truth, as expressed partly by natural selection and chiefly by the new theory of evolution to which the last chapter of this section referred at considerable length.

On the Darwinian theory itself, love and pity are products of natural selection, and are therefore justified, and must be assumed to have a value for and in evolution. They are as demonstrably in the ascendant, from the humblest vertebrates up to man, as the brain is, and can no more be called degenerations than the brain can. To turn round and condemn them in the name of evolution is therefore to deny evolution itself. But let us look at the facts: they will display the evolution of something which can only be called organic morality.

We are here concerned with that particular line of evolution which yields us the vertebrates, intelligence and man. The case of the line which yields us instinct, through the invertebrates called insects, is different, for the evident reason that the instinctive animal needs no help nor education, but is born perfect as far as it goes.

Organic, reproductive and moral evolution interdependent along the road of life

Let us note these facts for comparison when we come to look at intelligence. Along our line the facts, in brief, are that from the earliest fishes (to begin no lower) up to ourselves, the reproductive act increasingly displays a moral aspect. Reproduction, the production and care of other individuals, becomes the chief opportunity of altruism, which is other-ism. The reproductive function always tends to become more difficult and exacting with the increasing worth of the individual produced. The new individual is born, not more and more efficient and competent as life ascends, but *less so* — the supreme paradox of the living world. It thus needs the greater display of what we have called organic morality on the part of its parents. Thus organic evolution, reproductive evolution, and moral evolution are interdependent, along the great line which leads through the vertebrates to man — the only open road of life

The highest vertebrates, the mammalia, of which man is the last and highest, surpass all the past. In the mammalian mother, organic morality has advanced further than in any of her predecessors, for she possesses bodily organs solely designed for the benefit of others — the unique distinction of the mammalian breast. As the mammalia ascend, the periods of gestation or expectant motherhood, and of lactation or nursing, in general, increase, reaching their longest in human beings and elephants.

The evidence further shows that the more the mother gives, the greater her devotion and labor and faithfulness, unconscious and conscious, "organic" and super-organic, the more helpless is her offspring, and the longer so. Contrast the young reptile, or even the chick, with the kid, and the kitten, born blind, lame, helpless. But then compare kid or kitten with a baby, say at six weeks old. The animals can now feed themselves as they run about. The child is still helpless. It needs incessant care in order to keep it alive. It is unarmed, naked, defenseless; a poor match for the kid of its own age. Yet man survives. This creature, not one specimen of which would survive its birth for twenty-four hours if left to itself, becomes the dominant species of the earth, the highest form of life that we yet know.

Natural selection selects love and morality because they serve life

Natural selection is by no means mocked. The baby has, or rather its mother has for it, some factor of "survival-value" which entitles it to survive. Its name is love. The higher the race, the more helpless are the young at birth, the longer do they need parental care, and the more assiduous must that care be. This parental care furnishes the baby, for the time, with the weapons of its success in the struggle for existence. It is uniquely deprived of other factors of survival-value, being at its birth the most helpless of all the forms which life has ever produced; but parental care constitutes for it a factor of survival which more than compensates for the absence of all the rest. We may and must freely grant that natural selection is impersonal and non-moral. It has no bias in favor of beauty of body or the "beauty of holiness". It rejects whatever cannot live — altruism in excess or bacteria that are not poisonous enough. It selects or tolerates whatever can live, without a trace of moral bias. But it is concerned to select the fittest, and thus, in man, it selects the most moral.

Morality and love, then, are not an absurd invention of the priests; sympathy is not "the morality of slaves", invented by an enslaved people under the name of Christianity, as Nietzsche declared; nor does it oppose the operation of natural selection, which Nietzsche and the neo-Nietzschean eugenists declare to be the only means of giving us the superman. The statement of natural history is that *natural selection selects morality.* Love is older than mankind, far older than any existing church or creed.

The enemies of love have appealed to natural selection; and to natural selection they shall go. Even this mechanical, negative, material, lifeless factor of the evolution of life returns a verdict in favor of morality, as the emergence and triumph of love prove. But we have already learned that natural selection creates nothing, whatever it may select, or rather whatever it may tolerate. We still require, therefore, a positive explanation of the emergence of love. It can, of course, only be the explanation of Shelley and Spencer and Bergson — the explanation here given. The evolution of love and of intelligence is explained because love and intelligence serve life, or because they are native in the primal essence of life.

Life a progress — each generation leaning over the next in love

The aim of life is to live and to transcend itself. Hence, as we have learned, its invention of death in the service of higher and fuller life to come. Life is a progress and a movement. In its course it makes individuals, whom we think of as *things*, though each of them is really part of a progress. "At times, however," says Bergson, "in a fleeting vision, the invisible breath that bears them is materialized before our eyes. We have this sudden illumination before certain forms of maternal love, so striking and in most animals so touching, observable even in the solicitude of the plant for its seed. This love, in which some have seen the mystery of life, may possibly deliver us life's secret. It shows us each generation leaning over the generation that shall follow. It allows us a glimpse of the fact that the living being is, above all, a thoroughfare, and that the essence of life is in the movement by which life is transmitted."

Finally, we have to justify the assertion that intellect and love, which seem so different, are interdependent, and in so doing to explain the paradox that the most competent race is born the most helpless. This has been worked out years ago by Dr. McDougall, particularly in his book "Body and Mind: A Defense of Animism", published in 1911, and in masterly fashion by Bergson. In general, while instinct cannot learn, it need not, for it is born perfect within its limits, which it will never transcend. *Intelligence has everything to learn, but it can learn everything.*

Because intelligence can learn everything it has everything to learn

An intelligent being bears within himself the means to transcend his own nature, as man is always proving. To intelligence, and to intelligence alone of the three directions in which life has evolved, the road is open to the infinite. Instinct is lost in novel circumstances, and can answer no questions. Intelligence can adapt itself to new circumstances, answer novel questions, and, in its greatest moments, can create new circumstances and ask supreme questions, even though it cannot answer them all as yet.

But just because it can learn everything, it has everything to learn. Hence the key to the paradox, that the more intelligent a race the more helpless is it in infancy. To be born competent is to be born incompetent for progress. The infant is helpless because of the nature of the endowment with which it will some day help itself to the earth and the fullness thereof. And because it must be helpless, it must have the care of parenthood or foster-parenthood.

Our long argument thus culminates in certain great propositions which may here be reasserted for convenience of the reader in a short and concise form. Not only is the Nietzschean doctrine that morality is a product of man in slavery untrue, but the truth is that man is the highest product of morality. The law of nature is: *No love, no intellect; no morals, no man.* The triumphs of man are the triumphs of woman. Baby-saving is intellect-making.

This particular fact of helplessness in the human infant is due to his unique departure from the instinctive endowment of life, skilled but rigid; and the unique prolongation of his dependence is due to the unique extent to which intelligence develops in him. Indeed, to the end he is dependent upon the generations before him. Their skill and sacrifice and care have endowed him with the conditions which make his life as an intelligent being possible; his ancestors watch over the bed of the man in his glorious prime, and guide and guard his day. This is the forward purpose of life, still justifying itself. Sacrifice, devotion, love, alike for those we have in our arms, and for the future which we shall never see: these are the very conditions of the life of an intelligent species, reminding us of the fine sentence which contains the essential conclusion of Herbert Spencer's philosophy: "A transfigured sentiment of parenthood, which regards with solicitude not child and grandchild only, but the generations to come hereafter, fathers of the future, creating and providing for their remote children."

It would seem, then, that the gospel of force is based upon shameful ignorance of the facts of biology. These facts teach us that altruism has been an indispensable factor not merely in the ennobling of human life but in its actual production. They further teach us that morality is no artificial product, but an inalienable possession of humanity, older than all the churches, much older than human thought. Thus, though "Nature, red in tooth and claw", may appear indifferent to good and evil, her sun shining alike on the just and the unjust, yet every new baby teaches us that love is a cosmic product of which humanity itself is not the author but the fruit; and that, therefore, Emerson was justified when he said that "the universe is moral".

The untutored daily observation of all men in all times, and the theory of evolution, which is the highest product of the tutored observation of all times, alike teach us that altruism is an inherent factor in human life, older than all religious and ethical systems, and destined to outlive not, indeed, Truth, which "fails not, but her outward forms that bear the longest date".

PROGRESSIVE STAGES OF PLANT GROWTH

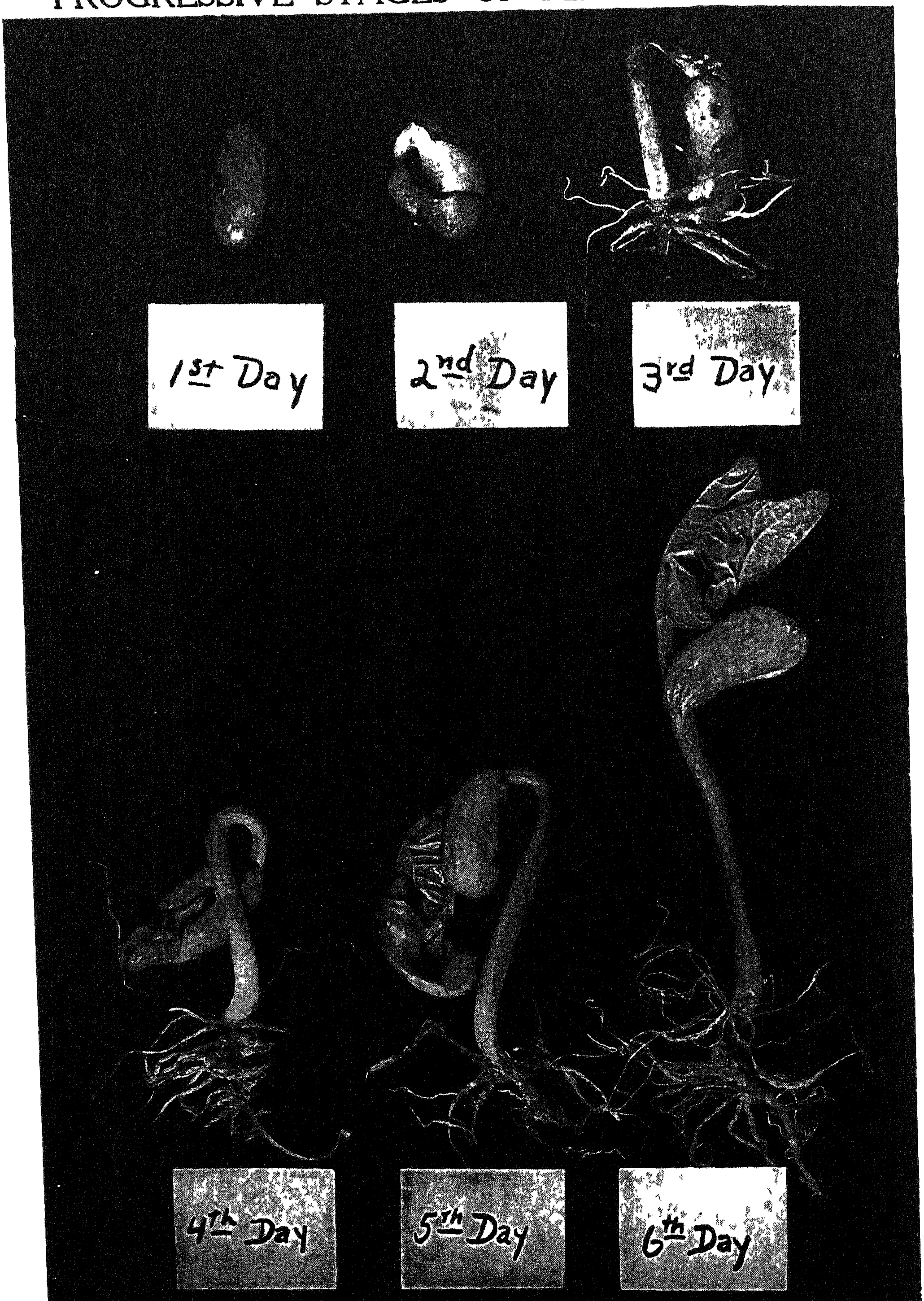


Photo N. Y. State College of Agriculture, Dept. of Plant Breeding

This photograph shows the progressive stages at germination of a bean seedling: (1) the seed as placed in moist soil; (2) seed coat breaking away and stalk emerging; (3) stalk elongated and secondary roots appearing; (4–6) plumule emerging between cotyledons and assuming erect position. Note adherence to roots of soil particles firmly held by microscopic root hairs.

A PLANT'S FIRST GROWTH

Conditions of the Germination of Seeds, and Their Purposeful Stroke Downward and Upward

EASY EXPERIMENTS WITH THE BEAN

WE have now to take up some of the further problems of growth and the function of reproduction; and at this stage we shall confine ourselves to the study of these processes as they are connected with seeds. At a later stage, when we study the organs of reproduction in flowers, for example, we shall have to consider some further points.

The most common way to raise a crop of almost any plant is by the sowing of the seeds produced by a former generation of the same species. True, as we have seen, there are other ways of producing new plants, but the sowing of seeds is the process that rises in the mind as the initial stage of the production of a new crop. It is therefore essential that we should understand something of the nature of a seed, and of its marvelous capabilities. To the ordinary mind these are wrapped in considerable mystery, all the more obscure, perhaps, from the fact that the many different processes in connection with seeds are hidden from our observation, inasmuch as they occur under the ground. Some of them, too, are of such an extremely delicate nature, and on such a small scale, that it is necessary to call in the aid of the microscope, or at least a magnifying-glass, in order to observe them.

Still, there are some seeds sufficiently large and sufficiently common to enable them to demonstrate all the important processes quite easily. Anyone who chooses can study for himself the structure of a seed, and with his own eyes watch its development from the very earliest stages, until the plant itself is formed.

No better example for this purpose could be selected than that of the common bean, for it may be taken as a type to indicate the general structure of a seed. The wheat-seed also may very well be examined; and the illustrations in this chapter indicate clearly the different stages of development, and the structures concerned, which we are now about to describe.

If the pod of a leguminous plant, such as the bean, be opened when the seed is nearly ripe, it is found that each of the seeds is attached within by means of a short stalk.

This stalk, or "funicle" as it is called, is really the means of communication between the maternal structures and those of the seed itself, and it is through it that the nourishment from the parent is transmitted for the development of the young seed. By and by the stalk dries up, and so ultimately allows the seeds to detach themselves from the parental connection. In order to ascertain exactly what such a seed is made of, it should not be allowed to become shriveled up, but rather should it be soaked in water for a few hours, by which means its separate parts can be more readily distinguished.

The outer covering of such a seed is smooth, of a yellowish color, and is characterized by a black mark at one end, which is known as the eye or "hilum". This represents the point at which the seed was attached to the funicle within the pod during its process of ripening. Close beside one end of the eye of the bean there can be seen, with the aid of a magnifying-glass, a very small aperture.

Its presence can be demonstrated in a soaked bean by gently squeezing the whole seed, when a little water will bubble out at this spot. Obviously the aperture, therefore, forms a means of communication with the interior, and apparently the only communication. There is nothing else on the outside which is noticeable.

The outer coat can be very easily removed by cutting round the edge of the seed and stripping it off. When this has been done we see that we have removed a sort of membrane, tough, and not quite transparent. This is the "testa". Within it the true seed lies, seen to be oval and somewhat flattened, and separable into two distinct halves, or "cotyledons", united by a little projecting portion known as the "radicle", one end of which is inserted in a hole in the testa, which corresponds in position to the aperture already mentioned. The other end lies between the two cotyledons, as is distinctly seen if one of these halves be removed, when the bent radicle remains attached in position to the other. The seed, therefore, in this undeveloped stage is seen to consist of testa, radicle and two cotyledons.

This is a simple enough structure, but it is, nevertheless, sufficient to contain within it all the possibilities for the growth of a complete bean plant; and the function of the various parts only becomes obvious when this seed, or bean, is either placed in the ground and allowed to grow, or else put under such other conditions of temperature and moisture as will stimulate it to growth similar to that which would take place if it were in the ground.

How the seed begins to send out the root and stem

Let us suppose that the seed is placed in such conditions, and that we can watch what happens. The first thing to which our attention would be drawn is that one end of the bent radicle grows longer, and very soon forces a passage through the seed-coat. The spot where it emerges through the coat is very close to the minute aperture, or "micropyle", already mentioned, but not actually through it. Further elongation of this radicle soon causes the seed to assume the shape seen in figure 4 of the illustration on the page facing. A glance at this illustration suggests that the elongated radicle is becoming a root, and, indeed, that is the case, for this is the root of the new plant.

Part of it, however, remains between the two cotyledons; and this part, which is curved, also forces a passage out of the opening in the coat of the seed and grows upwards. Just as the lower portion suggested the growth of the root, so does this second outgrowth, as it straightens itself upwards, suggest a stem, and, indeed, this is a new stem from which the leaves are about to be developed. At this stage the appearance is that shown in figure 5, and we have what we may term an "embryo plant". The root and the stem together thus form an axis, passing through, as it were, the two cotyledons; and these two structures, root and stem, are known as the "primary axis" of the plant.

If we wish to know where the root begins and the stem ends, it is necessary to make a much closer examination of the structure within the axis itself. It is noticed that the upper part of the stem as it forces its way out from between the cotyledons is bent upon itself, and it remains in this curved attitude for some time. This forms a kind of protection for the developing tender leaves; and although this is not obvious in a seed that is being grown simply in water, it will be quite clear if a seed in the ground be examined.

A simple method by which germination can be watched

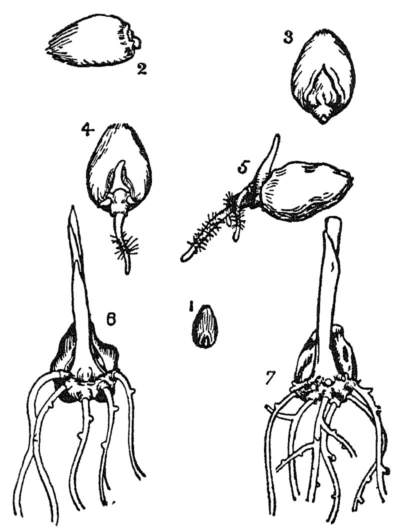
Any who wish to observe for themselves the processes we have just described may readily do so by simply taking a few beans, soaking them in water for twelve hours, wrapping them up in some thick, damp flannel, and placing them between two plates, so that one plate covers up the beans in the flannel, and keeps in the heat — just as one would place a piece of toast to keep it warm. The beans can then be examined at intervals, and the flannel kept damp, when the appearance of the radicle and the curved plumule may be easily seen.

As long as the seed is in the pod, it derives its nourishment from the parent plant from which it grows, but when it gets to the ripe stage it passes into a curious condition of inactivity. This stage may last for a very long time, during which no signs of life in the seed will be apparent at all. How long a seed may remain in this dormant, inactive condition is a much-disputed matter, and depends a good deal upon the kind of seed concerned, as well as on the environment in which it happens to be. It is a very curious stage, and is not entirely understood, but this much is certain: the embryo within a dormant seed will not live long unless the seed was thoroughly ripened first. A good deal, too, depends upon how the seed is kept afterwards. Most of the seeds used in gardens, or for agricultural crops, fail to germinate if kept for more than ten years or so, and a good many will not survive nearly so long a time. In fact, two or three years is the limit for some. On the other hand, seeds have been said to have retained their power of germinating for much longer periods.

This capacity for germinating, which constitutes, of course, the whole value of a seed, depends upon at least the following factors: the embryo in the seed must be alive; it must have supplied to it a certain amount of water; it must not be subjected to too great extremes of temperature; it is imperative that it shall have a supply of air or oxygen.

Curiously enough, it is quite impossible to tell by simply examining the outside appearance of a seed whether it is alive or dead. That is to say, external symptoms do not afford obvious evidence of the life of the embryo. The seed may be discolored, apparently dried up, wrinkled and otherwise disfigured to such an extent that it would appear hopeless to expect anything from it, and yet if it be placed under suitable conditions germination will follow. On the other hand, externally the seed may represent every appearance of being in a good condition, and yet when planted may fail to germinate, because the embryo within is dead. It is true, at the same time, that there are some seeds whose power of germination can be roughly, or partly, estimated by their color, and particularly by their brightness, but no great reliance is placed upon such unreliable methods; and all seeds that are to be used should have their germinating power tested by putting samples of them under suitable conditions.

The most usual cause of failure for germination is that the embryo within the seed has perished. We are apt to forget that this is a living structure, capable of retaining its life for a wonderful length of time, but not capable of so maintaining it indefinitely. Thus, in the case of the wheat-seed, seeds which have been kept for more than ten years are found to be quite dead, and even in three-year-old samples there will be far fewer seeds germinating than in a sample of wheat sown in the season following the crop. So the germinating capacity of the seed obviously deteriorates with its age. This is, of course, a very practical question, because it becomes of importance for the gardener and the farmer to have some kind of idea of the length of time he may keep seeds stored without impairing his chances of securing a reasonable crop.

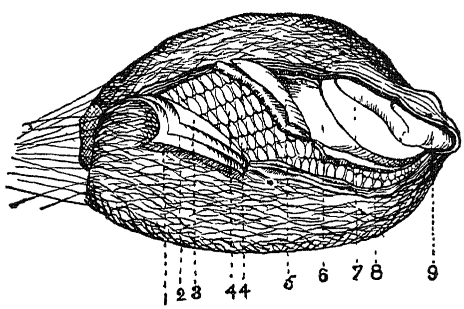


GERMINATION OF A SEED

1, Grain of wheat, natural size; 2, enlarged, showing protrusion of embryo on right; 3, the tip of the radicle beginning to appear; 4, a later stage, showing plumule growing and root hairs on radicle; 5, 6, 7, progressive stages, showing growth of plumule and roots and shrinking of the seed.

The following table is given by Professor John Percival to indicate the time beyond which it is inadvisable to use the seeds mentioned.

Wheat 2 years
Oats 2 years
Barley 1 to 2 years
Rye 1 to 2 years
Corn 1 to 2 years
Peas 4 to 5 years
Beans 4 to 5 years
Buckwheat 2 years
Turnip 3 to 4 years
Swede 3 to 4 years
Mustard 3 to 4 years
Mangold 3 years
Carrot 3 years
Cabbage 3 to 4 years
Kale 3 to 4 years
Kohlrabi 3 to 4 years
Clovers 2 to 3 years
Sainfoin 1 or 2 years
Lucerne 3 or 4 years
Most grasses 2 or 3 years



THE PARTS OF A GRAIN OF WHEAT
1, Epicarp, 2, mesocarp, 3, endocarp; 4, testa; 5, seed-coat; 6, endosperm; 7, plumule; 8, cotyledon or scutellum; 9, radicle; 7, 8 and 9 comprise the embryo.

The next condition necessary for germination is that there should be a sufficient quantity of moisture in the form of water. This can be seen at once experimentally by keeping seeds dry at different temperatures where they have an exposure to air, when it will be found that no growth occurs. On the other hand, if they be allowed access to moisture, not merely in the ground but even in a dish, the moisture is enabled to penetrate the seed-coat, and so reach the interior, passing especially through the minute aperture of the micropyle. This moisture very soon reaches the radicle, which, as we have seen, is the first part of the embryo to make its appearance. The immediate result is that the bean, or other seed, swells and softens, these two changes preceding the appearance of the growing radicle.

Other conditions necessary for germination of the seed

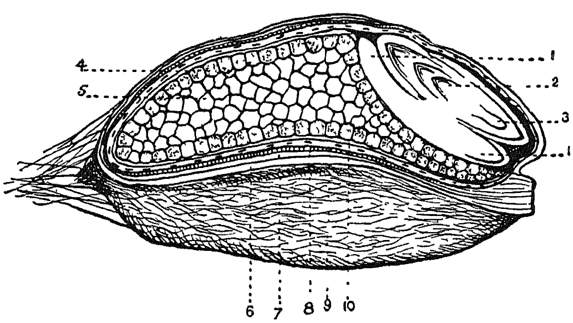
But not only is it necessary that the embryo should be alive and healthy, and that moisture have access to it in order that germination may take place — a certain amount of heat is also required. Gardeners and farmers observe this when they sow beans or other seeds in the ground during the winter months, when, instead of the radicle making its appearance in a few days as it does in spring and summer, the seed remains dormant until the temperature rises. There is great variation, however, in the actual temperature required to start the germination process Some embryos make their earliest growth when the weather is only just above freezing-point, other species requiring much warmer surroundings. In every case there is a temperature at which that particular kind of seed germinates most readily. In the case of the bean it is about 28° C.

A still further necessary condition of germination is a supply of air or oxygen, although it is not quite so easy to demonstrate the necessity for this. Still, it can be done by placing the seed in an atmosphere of hydrogen, or some other gas which displaces the oxygen of the air. Then it is found that, even though both moisture and adequate heat be supplied, still germination does not now take place.

These three necessary factors of moisture, oxygen and warmth immediately suggest to us that we are dealing with an actual process of life itself; and when we make a further experiment and notice that the growth of the seed does actually absorb oxygen from the air, and give off carbon dioxide into the air, we are still more convinced of the fact, because this is precisely what happens in the respiration of ordinary living creatures. Another proof can be offered in a simple experiment. If a few beans be placed in a bottle containing ordinary air, and the neck of the bottle be corked up, a chemical test at the end of twenty-four hours will show that the air has been replaced by carbon dioxide gas, the oxygen obviously, therefore, having been utilized by the seeds.

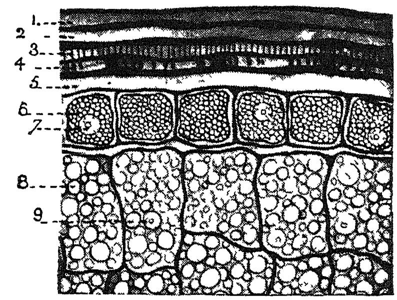
The actual part played by water in the process of germination has been already partly discussed in earlier chapters, but the additional point may be mentioned here that it is clearly of the greatest assistance in so softening the tough seed-coat as to enable the embryo to start growth and penetrate its covering.

The earlier stages of growth, such as those illustrated in our pictures, depend entirely upon the two cotyledons for their supply of nourishment. These cotyledons, at first thick and bulky, will be observed, as growth goes on, to become reduced in size, getting considerably thinner. As a matter of fact, their interior is a store house filled with food for the maintenance of the growing embryo; and this suggests to us another important function on the part of the moisture absorbed by the cotyledons — namely, that it dissolves the nutrient matters and enables them to be carried to the embryonic areas themselves, and especially to the radicle and the young stem, as they respectively appear. The earliest stages of germination cannot occur in such a seed as the bean without the presence of the cotyledons, as can be easily proved by cutting off the radicle and the stem of the embryo immediately they have made their appearance and pushed themselves through the seed-coat. It will then be found that development ceases, the supply of nourishment having been cut off.



LONGITUDINAL SECTION OF A GRAIN OF WHEAT

1 Cotyledon or scutellum; 2, plumule; 3, radicle; 4, cells containing aleurone grains, 5, cells containing starch grains; 6, epicarp, 7, mesocarp; 8, endocarp, 9, testa, 10, seed-coat, 4 and 5 comprise the endosperm.



CROSS SECTION OF A GRAIN OF WHEAT HIGHLY MAGNIFIED

1, Epicarp; 2, mesocarp; 3, endocarp; 4, testa, 5, seed-coat, 6, aleurone grains in cells, 7, cell nucleus; 8, starch grains in cells, 9, cell nucleus.

One of the most interesting points in connection with the process we are discussing is that of the movements that take place in the different parts of the young growing plant. Such movements are quite clearly indicative that we are dealing with a living young thing and one of a specific type. Thus, when the bean planted in the soil has reached a stage at which the radicle appears, this structure is observed to turn at once downwards into the soil, and continue to grow in that direction This happens no matter in what attitude the bean was originally placed.

The stem, or plumule, exhibits movements equally definite, but exactly opposite in direction From the very moment when it emerges from the seed-coat between the cotyledons, its tip, which is at the end of its curved portion (see figures 4–7, page 1811), begins to grow upwards in the opposite direction from the root; and, again, if the seed be uprooted and the position reversed, the experiment fails, the stem once more asserting its inherent living tendency to seek the surface of the soil. A very interesting experiment, that illustrates these marvelous movements extremely well, is to sow a number of beans in a shallow box, placing the seeds in a variety of different positions. If they be examined at the end of a week or so, the above facts will be made obvious.

We have taken the case of the bean as an example of the process to be noted in germination because the seed itself is a common one, and sufficiently large for its structures to be easily examined. It must not be thought, however, that the process differs in any essential particular in the bean from that which takes place in other seeds.

While it is, of course, perfectly true that seeds differ immensely in their appearance, size, color, weight, texture and so forth, they nevertheless all have this at least in common: that every one contains within it a young embryo stored and protected between the seed-coats. These latter may be large or small, but the proportions only differ, not the structures.

There are few exceptions to this rule. The exact manner in which the embryo is disposed within the seed is not, however, the same in all kinds. Its size, its manner of appearance, and its rate of germination vary very considerably in different species.

In the case of the seeds of the white mustard plant, the two cotyledons do not remain inside the seed-coat and below the soil as they do in the bean, but escape together from the seed-coat and actually come up above the soil surface, where they soon assume the appearance of ordinary green leaves. In fact, they are the first leaves of the mustard plant. A little later the stem appears between the two, and as it grows upwards develops from itself the secondary or rough leaves of the mustard plant.

It may be well to mention in passing, since the term is in very common use, that all plants the embryos of which are characterized by possessing two cotyledons receive the name of "dicotyledons". This group is a very well-known and numerous portion of our flowering flora.

Some seeds, however, do not depend entirely upon the cotyledons for their storage of food, even though they belong to the group of dicotyledons. For example, the seeds of the ash and the potato, both of this class, have a store of food quite distinct from the cotyledons. When such a separate store of food exists it is known as "endospermous", and the seeds possessing this store are termed "endospermous", or "albuminous", in distinction to those of the bean and mustard type, which, having no separate storage of the kind, are termed "exendcspermous", or "exalbuminous".

Finally, a grain of wheat is not exactly a seed but a mass of nourishment that contains a seed. When germination occurs, the seed within the grain gradually comes to occupy the whole of the interior. The embryo takes up only a small part of the space, mainly utilized by a store of floury nourishment. When the embryo begins to grow it is seen to consist of a shield, or "scutellum", attached to this is the plumule, this exhibiting a short stem with leaves of a sheath-like nature. Three rootlets usually appear. As the embryo grows, the endosperm diminishes, so it is obvious that this endosperm is the store of food upon which the young plant is dependent during its early growth. The shield has the function of transferring the food to the different parts of the growing plant.

ANIMAL HOME BUILDERS

The Intelligence That, through the Beavers, Finds Expression in Elaborate Engineering Works

THE MASTER CRAFTSMAN OF THE WILDS

MAN was not the first home-maker. He was not the first engineer. He was not the first to make provision against the morrow. He was anticipated in each sphere by the brute creation. Insects and birds, and certain of the mammals, set an example that he was slow to copy. Perhaps the imitation was unconscious; perhaps it was partly conscious.

We have learned from the wild animals how to hunt them, and what it is safe to eat, and it is not unlikely, therefore, that primitive man may have got some of his first ideas in engineering from the quadrupeds about him. Indisputably, the cave dweller must have envied the beaver its lodge and the burrowing creatures their subterranean cities. With his mind, with his hands, with opposable thumbs, with his erect carriage, he has outstripped all the rest of creation. The results that he has attained are, of course, incomparable, but the achievements of the beaver are almost as incomparably ahead of those of all other animals—"animals" in the common acceptation of the term.

The life of the beaver is really more highly organized than that of the mightiest gorilla or of the astutest monkey. The rough shelter of interlaced branches of the tree upon which it squats is the only attempt at a dwelling made by any of the exalted order of Primates. Yet the brain of the ape or monkey is the finest brain in the world next to that of man. It is surprising that with the imitative faculty so highly developed, the Primates have never essayed home-making. One difficulty, of course, is that Primates and beavers occupy different regions.

But it is only the lower animals that build homes and store up food. Their habitations are regarded as evidence of degeneration in some animals—as evidence that failing by other means to keep pace with the tide of evolutionary progress, they have had to crawl below ground. This argument does not apply to the animals with which this chapter deals, a group belonging to the rodent family, a numerous and specialized assemblage of mammals, the majority of which will be separately considered. The list is headed by the beaver, our finest natural engineer. He was the first to throw a bridge across a stream, and he remains the only animal capable of the feat. He was the first mammal to build a home above ground, and today man is his only rival.

It is impossible to guess how the habit originated. The food of beavers consists in the main of the bark and twigs of trees, notably the willow and poplar; but in summer, when they leave the river and wander inland, they flourish upon corn and grain. It is suggested by a thoughtful naturalist that at some time early in their history a beaver may have gnawed through the trunk of a tree overhanging a rivulet, till it fell across the stream and formed a natural barrier, that held up the water to a permanent depth. To suppose that this hypothetical pioneer immediately grasped the significance of accident, and finished the dam, and that his progeny at once learned the lesson and adopted the plan, is to credit the beaver brain with an intelligence and reasoning power altogether too high. But the process must have come about gradually by some such means.

Had there been a beaver that could suddenly dam rivers, build lodges and make roads and canals for the conveyance of its materials; and had such an animal transmitted its gifts to its offspring, it would have become the ancestor of a type of animal that, supposing its gifts to be progressive, might have challenged man for the supremacy of the world. For, eliminating all the fiction about the beaver's engineering prowess, its work remains a marvel of the animal world.

In this case not only does the environment affect an animal, but the animal in turn skillfully utilizes the environment. The beaver must select its stream and operate according to the problems presented by the chosen building site. It must dam the stream for the purpose of maintaining a constant depth. Having secured its waterway, the beaver must construct a home that is safe from the attack of the wolverine and other enemies and that will at all times provide access to a sufficient depth of water free from ice, in order that the food stored beneath the stream may be reached.

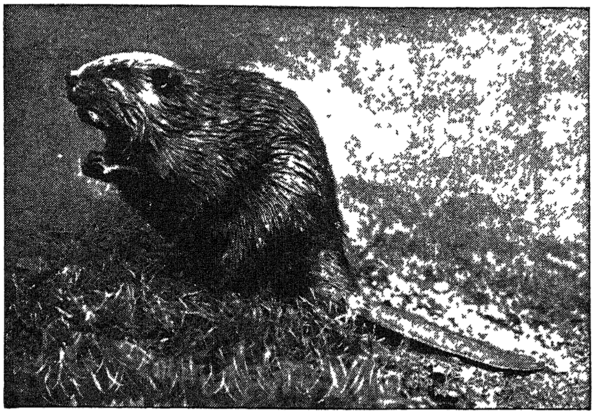
Next the beaver must fell timber and construct canals for the purpose of conveying those fallen logs to the water. Strike out every suggestion of fancy and embroidery, and the feats of the beaver are still some of the most challenging facts in animal psychology. Says Auguste Forel: "It seems to require much less nervous substance for fixed or instinctive reasoning than for reasoning actual, individual, new and combinative." And he describes instinct as reasoning organized, systematized and automatized. Let us see whether the beaver's work suggests reasoning or only obedience to blind impulse.

Beaver works are carried on for hundreds of years; but this can only be in a low-lying, swampy region, where the beavers may run canals far into the woods, and so not consume the trees faster than new trees can grow. Let us imagine a couple of beavers beginning a new construction project. We have to remember that in some parts of North America and in Europe, where these animals have long been persecuted, they may occasionally lapse into becoming mere burrow-makers, inhabiting the banks of streams. The beavers we have in mind, however, are those that remain among the vanishing glories of the northern United States and Canada. The earliest duty of our pioneer subjects is to excavate a burrow in the bank, or throw together a roughly built lodge to serve as a temporary home while a larger and more durable permanent mansion is prepared.

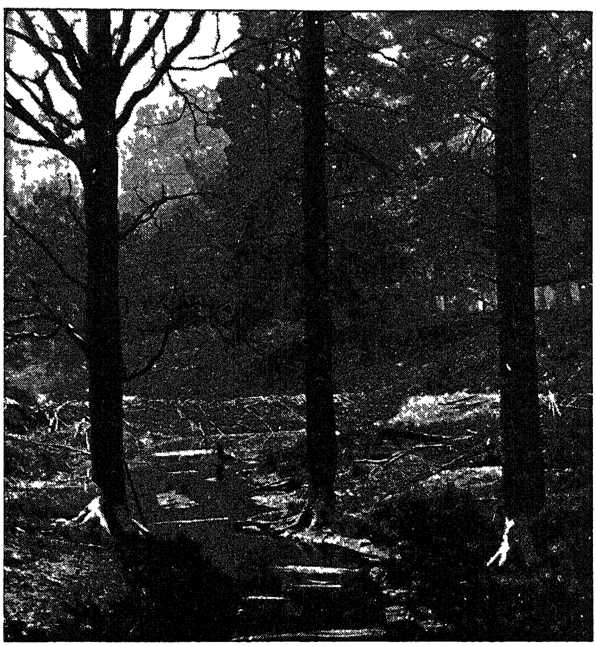

Union Pacific Railway

The entrance to this beaver lodge, constructed of mud and branches, lies below the water's surface.

The first problem to be determined arises from the stream. If it is a small and sluggish stream, a light dam of woodwork will suffice. If it is a swift-flowing rivulet, the case demands a more ambitious effort, and the dam must be made like a wall. The shape, too, has to be determined. A straight dam serves to check a gentle current of water, but to withstand a rapid flow a curved dam, with the convex face opposed to the current, must be built. Here, then, are problems calling for "reasoning actual, new, and individual". A decision having been reached as to what form the dam shall take, the beavers set to work to cut down trees. Those nearest the water and inclining towards the stream are chosen, and gnawed through near the root. As a rule, but not always, the tree falls towards the water. The boughs are then bitten off and peeled. The bark and thin twigs serve for food; the thick boughs themselves are gnawed through into suitable lengths for the dam. The trunk of the tree is similarly served. The logs are rolled into the water by the builders, who use their forepaws for the purpose, and push with their bodies, raising themselves upon their hind legs and using the heavy tail as a lever. It is to be noticed that the thicker the branch or trunk, the shorter are the sections into which it is cut, obviously in reference to the strength of the beaver.


THE SUPREME NATURAL ENGINEER — THE BEAVER

The foundation of the dam may be either of mud and stones or of brushwood, or both. In either case the logs have to be securely anchored to guard against their being floated away by the stream. This is effected by their being thrust into the mud, or into brushwood already so attached. In the case of a lighter dam, building with logs and twigs now proceeds apace. Sticks and poles and twigs are interwoven and plastered with mud, so as to form a substantial but not invincible barrier. In the case of the "solid-bank" dam, as it is called, less wood is employed, mud and stones taking its place. The stones weigh from one to six pounds, and are carried held against the beaver's chest by the forepaws. Mud is transported in the same way, and beaten hard with the paws. The heavy trowel-like tail is not used for the work, but is simply the rudder, though the report with which it strikes the water as the animal plunges in may be employed as an alarm signal.


THREE TREES IN COURSE OF DESTRUCTION BY BEAVERS, WHOSE DAM IS TO BE SEEN IN THE BACKGROUND

It probably took man a long time to make a sluice for his lock-gates The beaver has his sluice, too. In the case of the woodwork dam interstices between the logs and twigs afford an outlet for surplus water by percolation, but it is different in the wall dam. Here the beaver deliberately leaves an opening at the summit, a well-defined channel through which the dammed-up water can rush when it reaches a dangerous height. Moreover, the size of this sluice is regulated by the beavers in accordance with the condition of their pond, being widened in presence of a freshet, and narrowed when the water is low. Attention is given constantly, so long as the beavers are in residence, to the stick dam, to guard against too rapid percolation and to the making good of waste at the base as the result of natural decay of materials. It is not uncommon to find one dam supplemented by a second, either close at hand or at some little distance down the same stream. This may be made in order that the one may serve as a sort of bulwark to the other, or it may be that the first has failed to dam up the water to a sufficient depth, owing to the configuration of the land, a defect which the second remedies. There are more plans in the work of a beaver than are dreamed of in the philosophy of most of us.

Our beaver friends are now ready to start in building their permanent home

The dam built, ample water is secured in which the beavers may safely swim without observation in summer and winter, more especially in the latter season, for they may roam away overland in summer and come back in autumn to repair their work and make ready for the snows. The lodge has next to be made. Here, again, discrimination must be exercised. If there be an island in the water, the probability is that the builders will choose that. They may build on the dam itself, or they may choose the bank of the stream for the site. Lodges vary considerably in size and design; they are not uniform and unvarying, like the cell of the bee, but are adapted to the natural conditions and to the changing levels of the water. Where considerable rises of water occur, the home is generally upon the bank. Some of the lodges are built wholly clear of the water, with burrows running down from the interior of the lodge to the bed of the stream; others are made with one outer wall actually in the water. The structure is of wood and twigs, the logs varying in length from a foot to a yard, and the whole is heavily plastered with mud, which, freezing in the winter, makes the lodge a stout fortress, which even the powerful claws of the dreaded glutton attack in vain.

The arch no mystery to the beaver

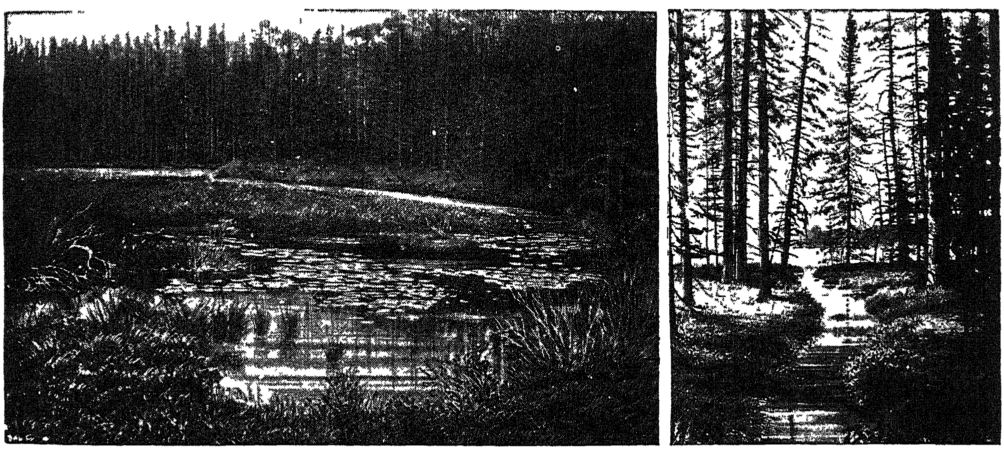
The beaver long ago mastered the mystery of the arched roof. His home consists of a spacious chamber, according to the age of the structure, and it is constantly undergoing repair and renewal. The chamber is oval, with a stout arched roof, and it may be eight or more feet in diameter in the case of an old lodge, while the height and breadth of the whole varies with age

Some lodges are occupied for many years. The interior is lined with mud and twigs and vegetable fibers, as are the tunnels, which communicate with the water. These latter are masterpieces of animal ingenuity. One is known as the "wood entrance", and is a straight, bold tunnel running sheer down into the water. It is through this that the beaver passes, laden with good cheer, returning with viands from his larder, which he establishes at the foot of the dam. The food consists of bark and tender branches of trees, and as these occupy some space, he must have a straight run up into the house for them, hence the bold tunnel left for their admittance. The second, and it may be the third, tunnels twist and wind before entering the water, and constitute the highways to the pond for all but foraging expeditions. It is perhaps not too speculative to imagine that the wood tunnel may be guarded in some way when not in use, or the devious highways to the water would be useless; an enemy would enter by the former without difficulty. All the tunnels are beautifully rounded, their roofs and sides and floors strengthened with twigs and fibers beaten into the soil.

So much for the dam and the lodge. The beaver is now free to enter the water at will. In winter he has a store of food hidden ready for his wants, and it matters not how severe the frost, there is clear water for him at the bottom to which his tunnels lead him. He runs from his lodge by way of one of these tunnels, enters the water — valves enable him to close ears and nostrils — he wanders under the water until he has got such food as he requires, returns by the wood tunnel, and shares his meal with his mate and offspring in as neat and effective a home as ever was built save by the hands of man.

Time brings changes even for beavers, and the day arrives when there is no more timber to be felled within easy reach of the river. He has cut down all the adjacent trees, gnawed them into logs, and rolled them to the water. The time has now arrived when he can no longer bring down his timber in this way; the ground is broken and uneven, the task of transport beyond his strength. It is a new problem, and the solution seems really more wonderful than the work on dam or lodge. The beaver calmly sets to work and makes a canal. Surely this is beyond the province of mere instinct.

Simply with his paws the beaver excavates a channel, and clears it of obstructions in the way of roots and weeds. Then he cuts a connection with the river, and floods his waterway. That gives him a passage, it may be of some hundreds of feet. Into this he rolls the logs which he has cut, and sends them down to the river or pond with all the assurance of the accomplished lumberman. But the ground makes a sudden rise, and it is necessary to carry his canal higher. He cannot, because he is unable to defeat the laws of nature and make water flow upward. This is another new situation, perhaps the most complex that he has yet had to face. He tackles it manfully. He builds a dam across the end of his canal, a catchwater dam, which collects all the water descending over a wider area from above, and cuts a canal in which the water so caught can run. He has made a canal lock! His waterway has risen a foot, and he now has another stretch of highway along which to float his logs down to the canal dam, over which he pulls them into the long stretch of water flowing into the main stream. It is no less a miracle of achievement for an animal than is the great Nile barrage for man. Man, with all his tools and appliances, excels the beaver's dams and canals more in degree than kind, and the beaver has only teeth and paws. Can it be wondered that the beaver is a sore puzzle to students of animal psychology, that they are driven to ask if something higher than instinct is not engaged in these marvels of engineering, of foresight, of planning, of battling with new and ever-changing conditions? Captive beavers do not encourage the belief in the possibility of higher mental faculties of the genus.



TWO CANALS DUG BY BEAVERS TO CONNECT TWO SMALL LAKES

U S Fish and Wildlife Service

The muskrat house — built primarily as a winter home — is a conical structure about five feet wide and three or four feet high and is constructed in shallow water of mud and the roots and stems of aquatic plants.

Beavers in a zoo construct their canals as they would in their natural habitat. They complete with logs and twigs the house that a keeper has started for them, and they plaster its roof with mud. The plastering and the canal constructing suggest the following of instincts, for the captives have not realized that they are in a new environment, which requires neither of these processes.

Though beavers have been mercilessly slaughtered, by trappers and lumbermen alike, almost to the point of extinction, conservationists, fortunately, are now working for the re-establishment of these large rodents. Still unique and a puzzle with respect to its mental attributes, this rodent ought to be treasured like the okapi of Africa and the American bison.

Another and more familiar home builder is the muskrat, which is found about streams, lakes and marshes throughout most of North America. It ordinarily lives in burrows in the banks of streams, building its grass nest above water level but still underground. But in marshes and along lake shores it often builds elaborate houses of rushes and other aquatic vegetation that rival those of the beaver. Since its heavy, waterproof fur holds out the cold, the muskrat is active the year around.

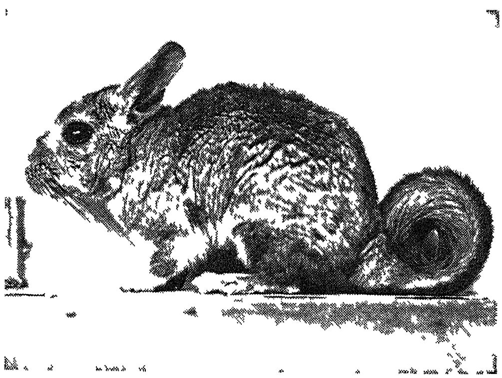
The engineering activities of the beaver are particularly remarkable; yet certain other mammals are gifted in this respect, and the structures they erect serve nature's purposes well. The North American ground squirrels, for example, excavate quite admirable underground dwellings approached by devious galleries and supplemented by twisting tunnels, which provide a ready escape in time of invasion by carnivorous foes. These animals lay in a bountiful supply of food for the winter season. Indeed, they are as provident as the ant, as an investigation of their stores of seeds and nuts will reveal.

The Asiatic susliks are expert miners, constructing deep burrows communicating with airy, roomy chambers Storehouses are established below to contain the winter's supplies. When autumn wanes, the susliks retire to their retreat, insuring security by blocking up the only entrance. In the spring they excavate an ascending tunnel running in the contrary direction to that by which they entered.

N Y Zoological Society

The antelope ground squirrel is a desert burrower.

The susliks have a system of sentries and lookouts; but it is not so highly developed as that which is found among the short-tailed ground squirrels, known as prairie dogs. These animals inhabit America's western plains. The older members of a community are stationed upon hillocks in order to survey the surrounding country; they give warning of an enemy's approach by means of a puppylike bark. The "dog town" in which they live is made up of large underground burrows, usually with built-up rims about their entrances. With all their care, the prairie dogs cannot keep out intruders, and they often suffer from attacks by the coyote, black-footed ferret and rattlesnake. The prairie dogs are for the most part herbivorous, subsisting on grasses, roots and grains.



The many types of ground squirrels generally resemble each other in habit and in the wonderful homes and tunnels that they construct below ground. Many lay up a store of provisions against the winter, but this is not the case with the woodchucks and prairie dogs, which sleep, or hibernate, so soundly through the time of frost and snow that they need no food. These two groups of rodents store up layers of fat, which suffice to provide energy enough for all bodily functions during the period of hibernation.

A remarkable miner is the South American chinchilla, or viscacha. This gregarious rodent, about the size of the prairie dog, is master of a remarkable home — an underground labyrinth of deep and numerous tunnels and chambers — and it has the instinct of a ragpicker. It stores at the huge entrance to its colony all the refuse of its food, and it roams far in order to gather things to add to this collection. When a friend of Darwin lost a watch on the Argentine pampas, he looked no farther than the home of the chinchillas, and there he found it, displayed to advantage amid bones, stones and thistle stalks. The chinchillas feed upon grasses, roots and mosses. Their soft, warm, pearl-gray fur is highly valued commercially, and for this reason these small rodents have been threatened with extinction.

The chinchilla (left) and prairie dog (below) are rodents that congregate in colonies, excavating vast networks of underground tunnels and caverns.

Both photos, N Y Zoological Society

The investigation of animal home builders suggests that at least some of them show, besides ingrained instincts, varying degrees of intelligence, which allow them to solve a variety of problems. Intelligent or not, in any case these home builders are an example of the phenomena of biological organisms engaged in establishing their niche, or place, in nature — a place that shelters their young and food stores and partially safeguards them from attack by their enemies.

A BRAIN CELL THAT IS A LINK OF THOUGHT

A MAGNIFIED PHOTOGRAPH OF A SECTION OF BRAIN SHOWING PART OF AN "ASSOCIATION" CELL, STAINED TO REVEAL THE REACHING OUT OF THE AXONE AND DENDRITES

A, axone, part of which has been cut off; *D*, dendrites; *N*, nucleus of cell.

MAN'S ESSENTIAL LIFE

The Dependent Yet Dominant Nervous System, For the Sake of Which the Other Systems Exist

THE SUPREME FUNCTION OF MIND

"WHAT'S past is prologue," as Shakespeare says. We have described bones and muscles and glands, the heart and the blood, the lungs and the digestion, but none of these is an end in itself nor all of them put together. In detail, they differ in man and the lower animals, but in no essentials. They clearly do not live for themselves, but for each other and for the nervous system, in which alone we find the characteristic organ of man They support the nervous system, and it rules them; but though the first statement needs no particular qualification, the second does.

Beyond doubt these various systems support or serve the nervous system Its powers of self-support are practically *nil*. It is shut away from the external world, and entirely depends for nourishment, ventilation and cleansing upon what the blood and lymph bring to it and take away from it. While other organs and tissues spend much labor in producing compounds that feed, or stimulate, or soothe the nervous system, it performs no such functions itself, we believe; and though it certainly produces many and various chemicals, these are highly objectionable to itself, requiring the most rapid and complete removal, and are of no use to the rest of the body, which, indeed, has to burn them up or throw them out entirely.

This dependence of the nervous system has reached an extreme point Other parts of the body have some power of what is called regeneration. Skin-cells and gland-cells, and many others, can divide and multiply, increasing their numbers or compensating for loss No nerve-cell can divide. The nerve-cells that are not too greatly poisoned can recover; we are learning that even nerve-cells that have been chronically poisoned with alcohol for years, and were thought to be dead, may recover if the poison is discontinued But if a nerve-cell dies, none other can divide so as to replace it. The infant at birth possesses all the nerve-cells it will ever possess. True, as we shall learn, not all may develop, but there will be no cell-division in any nerve-cell in any circumstances. The nerve-cell is so highly specialized that it has lost this characteristic and necessary power of all typical cells The consequence is that the nervous system is gravely limited in its power of compensating for damage, and therefore requires more care and protection than ever from those systems of the body which we have already described.

In return for their service it rules them, but the rule is much less absolute than we have until lately supposed Thus the white cells of the blood are not under the control of the nervous system at all, nor are the ciliated cells that line the respiratory tract and are found in many other parts of the body Again, though digestion is largely under the control of the nervous system, we find that the secretion of the digestive glands is by no means wholly under nervous control. The body is united in a double fashion — first, by the nervous system, and, second, chemically The chemistry of digestion is largely a series of reactions, of which each stage chemically conditions the next Thus the bowel produces a hormone called "secretin", which is absorbed and stimulates the pancreas to activity.

This is, then, chemical stimulation, chemical coördination of the body, quite distinct from nervous stimulation and coördination. We owe our gaining of this great new conception chiefly to the work of Professors Starling and Bayliss. We are learning that, both in health and in disease, the body is constantly producing and distributing substances now called "hormones", from the Greek verb *hormao* — I stir up, excite, summon, rouse to action. That is what these hormones do; and by them the various parts of the body are constantly sending messages and giving orders to each other, and thus achieving a unity and a common action, which is just what the nervous system also does in its way, and is no less indispensable.

The nervous system the system for which the whole body exists

From the point of view of the philosophy, the true science, of the human organism all this is very important, for it helps us to understand the real physiological relation between the nervous system and the rest of the body. The nervous system does undoubtedly rule, control, direct, coördinate, the rest of the body; and unless it does so things go utterly wrong throughout the entire mechanism.

But this does not mean that the nervous system exists only for that purpose, as has been supposed. On the contrary, the nervous system only does what is necessary *in its own interests;* and a vast deal of bodily management and regulation, we now learn, is done independently of the nervous system altogether, but nevertheless for the nervous system.

It is not the servant, not even the authoritative government, appointed by the people to serve them; it is the absolute object, end and aim of the whole body, which exists for it and for it alone. In the rest of the body, birth and death are continually occurring — skin-cells, blood-cells and so forth are born and die in perhaps millions daily. They and their fate are nothing. They are like the helots of ancient Athens, numerous, necessary, but allowed to exist only for the sake of the privileged few, in whom life reached its highest development. Just so nerve-cells are not born in the course of the history of the individual; or rather, they are born, once for all, long before his birth, and they last unchanged throughout his life, while birth and death go on incessantly and in their service.

The brain the relatively modern structure which reveals the soul of man

Ultimately, and in its essential nature, we begin to see, life is psychical. In another section of this work, where it was sought to reduce all existence to the fewest possible categories, life found no place. Ether and energy were regarded as ultimates, and a similar place was claimed for mind. Where, we may ask, does life come in? There is such a thing, and it is not named there. The question matters supremely when it is asked of the life of man. The answer is that life is ultimately not ether, not energy, though it is lived in ether, employs energy, and transgresses none of their laws. Ultimately it is psychical. Even in the lowest possible organisms recent work has demonstrated traces of choice and educability — traces of what can only be called mind; and in man supremely does life reveal its essential nature.

The overwhelming significance of this, for religion and for man's outlook upon the universe, must be evident, and we shall often return to it. If life be essentially psychical, if evidence of mind, however humble, be found wherever we look properly for it in the world of life, then the nervous system, and preeminently the brain, of man are simply those relatively modern structures in and through which the life of man, life as manifested in man, specially concentrates and reveals itself. The opposition between this view and that which regards man's mind as a consequence of his brain — a structure evolved by the ordered accidents of "natural selection" — is infinite, everlasting and all-important. The twentieth century may yet be recorded as that in which the mind of man walked out of the darkness of nineteenth century materialism into the wide light of knowledge, which asserts more surely and durably what the glaring superstitions of the past served rather to distort than to reveal.

The "psyche" diffused through all the lower organisms is concentrated in man

The first and the last function of life is mind; that was "in the beginning", and that comes first. The evolution of the nervous system in the animal world, culminating in that of man, simply means the superior concentration, effectiveness and intensity, even to self-awareness, of the dim psychical activity which is doubtless diffused through the general substance of lower organisms, and which unquestionably remains diffused through the various cells of our own bodies, as we soon learn when we study the behavior of white blood-cells, bone-making cells, ciliated cells and many more. As Bergson says: "The lower we descend in the animal series, the more the nervous centers are simplified, and the more, too, they separate from each other, till finally the nervous elements disappear, merged in the mass of a less differentiated organism. But it is the same with all the other apparatus, with all other anatomical elements; and it would be as absurd to refuse consciousness to an animal because it has no brain as to declare it incapable of nourishing itself because it has no stomach."

Mind finds expression chiefly through the brain, but also through the whole body

We affirm, then, that the nervous system contains and displays the essential life of man, or of any animal that possesses a nervous system, in the highest possible degree. But we do not assert that the essentially psychical character of life has been wholly withdrawn from the rest of the body. Very far from that, indeed, is the trend of modern psychology. On the contrary, when we study the nervous system on the assumption that the mind is a product of the brain, we soon learn that there are facts of mind the brain does not seem to account for.

We find that the spinal cord plays a part in mind. We discover the "sympathetic nervous system", and agree that this plays a part in mind. We discover that there are facts of mind, not clear and defined, like a logician's syllogism, but nevertheless part of the mind, which can only be referred to the organs of the body.

In ancient days, men thought of the liver as the seat of passion, the bowels as the seat of compassion and so forth. We do not think so now, but we do recognize that these and the other organs of the body play a real part in our psychical life. Mind is most displayed through the brain and the nervous system, but not through them only. In the concluding chapter of his "Autobiography", Herbert Spencer devoted much space to argument for the proposition that "the mind is as deep as the viscera" — that is, the internal organs of the body. No modern psychologist denies it. Mind is at the bottom of all our life. It was not invented by the brain, but it has evolved the brain as its most sufficient instrument.

The various forms of power over the body exercised by the nervous system

Thus, modern science seems to be steadily returning to the view of Plato, that the body and its organs are the musical instrument, the "organ", of the soul, which plays upon them, and reveals itself through them according to the degree of their perfection.

All this is anticipation. One other general consideration is necessary, and it is that the nervous system makes itself necessary to the rest of the body in a very remarkable way, not very long discovered, and not yet understood. Without any special study, we all know that there are nerves which order muscles, and nerves which record sensations; and we should say that these two express the whole relation of the nervous system to the rest of the body. But we find that, when the nerves running to any part of the body are divided, strange things happen. Of course, a muscle which has lost its nerve-supply is paralyzed; but let us take some other structure — say, the transparent front-window, or cornea, of the eye. This is not a muscle, and has no motor-nerves running to it. Sensory nerves run from it, and tell us when it is touched or scratched. But we find that, inside the bundle of fibers that we call a nerve, running from the cornea, there must be some which do not convey any information from the cornea, but do carry something to it.

In other words, we find that if the nerves of the cornea be divided, no matter how carefully it be protected so that nothing can touch it, soon it will undergo serious changes and will ultimately die. What has happened to it?

Why it pays all parts of the body to feed the nervous system

The answer is that the nervous system exercises, upon every part of the body, an influence regulating nutrition, which is called its *trophic* influence (compare "atrophy", and "hypertrophy"). Trophic nerves run to every organ and tissue, and keep them well. What really happens science has so far failed to find out. It might be merely that the blood-supply to the part is regulated by the nerves, which we know to be the case. But we may choose a tissue like the cornea, which has no blood-vessels in it, or we may check our observation in other ways, and we can prove that the trophic influence of the nervous system is something special, which does not depend upon, say, the exercise a muscle gets, nor upon the due regulation of the supply of blood to any tissue It is something apart, but its importance is beyond question, for there can be no health in any part of the body which is not receiving a proper supply of this trophic influence from the system. It follows that, if the nervous system be not properly looked after by the other tissues and organs, they very soon suffer in health. It pays them, so to speak, to look after their master properly.

What, then, is this nervous system, in which the life and mind of the body are so amazingly expressed, and raised to their highest in the self-consciousness of man? It is, of course, a collection of cells. They are not wholly collected in one place, but the quotation from Bergson has already told us that the closer grouping of the characteristic cells of this system, which we call nerve-cells, is a feature of the higher forms of animal life. The earliest nerve-cells are widely distributed throughout the animal body. To deny consciousness to such an animal is simply silly, it palpably wakes and sleeps, as we do; and if it is not conscious when it is awake, what is it when it is asleep?

The widespread nerves become linked up and grouped

But in time in the lower animals nerve-cells find that they can be vastly more effective when they are grouped together, just as a collection of strings and keys, forming a piano, is more effective than a scarcely connected number of such strings all over the house. Thus we get what are called nervous ganglia. A ganglion is simply a collection of nerve-cells. Where we find, say, four or five ganglia grouped together, probably at the front end of an animal, nearest its eyes and nose and mouth, as in the earthworm for illustration, we cannot easily deny to this collection the title of a brain.

This collecting and linking up of nerve-ganglia has proceeded much further in man than in any other creature, and has reached such an extent that we find very nearly all the nerve-cells in his body concentrated in a continuous structure or organ which we call the central nervous system. Thus, if one were to deprive a man of all four limbs, by amputation at the hip-joints and shoulder-joints, he would not be the poorer by even one nerve-cell.

There are no nerve-cells proper in the limbs, none in the skin, none inside any of the muscles of the body, with the great exception of the heart. There are, however, nerve-fibers which are prolongations of the nerve-cells located elsewhere. Yet the entire nervous system has developed from the skin layer of the embryo — that is, the layer next the outer world, which it is the business of the nervous system to deal with.

The withdrawal of the chief nerve-cells into a strong bone box

But, though it is now in better and really closer touch with the outside world, and has more power over it, it has withdrawn itself to an extraordinary degree, being not merely within the body and away from the skin, but being actually incased in a great box of bone through a few holes in which it transacts all its business. Thus only the brain sees, but lives in absolute darkness. The central nervous system can be, and will be, defined, and its outgrowths can be traced to the uttermost parts of the body.

Obscure puzzle of sympathetic nervous system and its sense of well-being

We also find in the body what we can scarcely refrain from calling another nervous system, and this is known by the name, given to it by the older anatomists, of the "sympathetic nervous system". Now this system is known as the "autonomic nervous system" to indicate that it possesses a certain independence of the "central nervous system". The nerve-cells of this system are much more scattered. They are not found at all inside the skull and backbone. But they form ganglia in various parts of the trunk of the body, and the most intimate connections exist between the central nervous system and the autonomic nervous system in spite of the above mentioned "certain independence" of the last system.

The largest ganglion belonging to the sympathetic nervous system is known as the "solar plexus", or "abdominal brain". This is by far the largest collection of nerve-cells in the body outside the skull and backbone. It lies behind the stomach, and is highly susceptible to blows. When we are hit in the "wind", or "knocked out", what has happened is that the solar plexus has been shocked by a blow; and we all can assent to the anatomical assertion that this plexus is linked up with other parts of the nervous system — not least with those which control our breathing or "wind".

But, really, the sympathetic or autonomic nervous system is still a great puzzle to anatomists, and so we had better only briefly discuss it here. The prevailing notion among anatomists is that the sympathetic nervous system is the oldest part of the nervous system of man, the part which has, so to speak, been left behind in the body-cavity when the rest of the nervous system has withdrawn itself into the skull and back-bone. But there are many difficulties in the way of this view, and perhaps the only thing certain is that we cannot afford to despise the sympathetic nervous system, for we do not yet know all of its functions. We know beyond doubt that it discharges most important functions, carrying many of the nerves that control the blood-vessels, for instance.

It also probably plays a very considerable part in the trophic function of the nervous system. But especially are we to realize that the sympathetic nervous system plays a much more important part in our *minds*, in our feelings of happiness or depression, "fitness" or slackness, good or bad temper, than we suppose when we think of the mind as if it were a secretion from the brain.

No one who has ever been "knocked out" should make such a mistake; if the solar plexus can give us such unpleasant feelings when it is out of order, may it not play a large part in other kinds of feelings when it is in order? Those who know how important for the life of man is his "organic sense of well-being" will begin to see the point. If a further hint be needed, let us consider what kind of sleep we "enjoy" when a heavy supper remains undigested, and is vainly churned in the stomach.

Nerve-cells of central nervous system remarkably unlike other body cells

And now for the central nervous system itself. It is essentially a collection of nerve-cells. With them there is found some connective tissue, blood-vessels and lymphatics, but the nerve-cells are the essence of the system. A nerve-cell, however, is in many ways exceedingly unlike all the other cells we know, and requires very special description. It has a variety of projections or processes, called "dendrites", running from it, or rather to it; and the modern theory of the central nervous system regards it as a combination of vast numbers of these units — each unit, a nerve-cell, with its various projections, or processes, being called a "neuron". This neuronic theory of the nervous system has held itself against all comers, and is now fairly established.

The center of each neuron is the nerve-cell itself, or the body of the cell, as we sometimes call it. The cell may take many forms, often being remarkably large and striking in shape, like the large pyramidal cells found at a certain level of a certain part of the human brain, and shown in the photographs in Chapter I of this group. A nerve-cell always has a large and vitally important nucleus, and this nucleus shows different appearances at different times.

An examination of the cells through which shines the light of the mind

But we never see its chromatin breaking up into chromosomes, nor any other sign of nuclear division. This nucleus cannot divide, but has devoted all its possibilities to its own individual development. The nuclei of the cells in the highest parts of the human brain are the most exalted forms of material structure in the world, for through them shines preeminently the light of mind. The idea of nerve-cells as electric lamps, arranged in a system, already presents itself, and will be found invaluable in helping us understand many facts of consciousness.

But, after all, an electric lamp is only a special place on the route of an electric wire, and similarly a nerve-cell has its connections. They grow not from the nucleus, but from the general protoplasm of the nerve-cell. The nucleus has no textural connection with the processes of the cell, but we know that if these processes be at any point separated from the body of the cell and the nucleus they forthwith die. Thus the nuclei of the nerve-cells have a trophic influence upon the processes of the cells, as they have through those processes, or nerves, upon all the tissues of the body.

The changes made in the nerve-cells by muscular exertion

When we stain the nerve-cell in a special way we find that it contains a number of stainable, spindle-shaped lumps of something, which are certainly no part of the living protoplasm of the cell, but yet are a normal part of the cell as we see it. It has further been found that if an animal be allowed to exercise itself, or if nerve-cells be otherwise made to work, the nerve-cells involved, which can readily be examined if the exercised animal be killed and sections made of the appropriate part of the brain, are now almost wholly deprived of these so-called "Nissl's granules". We can only believe that they are a store of nourishment for the cell, which it uses when it is discharging energy; and their disappearance after work helps us to understand the profoundly important nervous element even in what looks like purely muscular fatigue. After a period of rest these granules are reformed in and by the cell; and we can scarcely help instituting the just comparison between what we see here and the case of the specks of pro-ferments found before, but not after, meals in the secreting cells of the digestive glands.

What may be seen in the photograph of a nerve-cell

The real protoplasm of the nerve-cell, apart from that of the nucleus, has lately been found to be of a most peculiar kind. There is very little of the ordinary protoplasmic network of a cell at all. On the contrary, we find what is shown in the photograph here reproduced. The body of the nerve-cell chiefly consists of fibers which run to it or from it, according as we like to consider them, and which simply run through the body of the cell from one process to another, if the cell has more than one. Indeed, these processes are cardinal parts of the nerve-cell; and the fibers which they contain and consist of are really the astonishingly specialized protoplasm of the cell-body itself.

Thus, in short, what we call a nerve, such as the ulnar nerve, or "funny bone", behind the elbow, is essentially a bundle of fibers which are really the extended protoplasm of a great number of nerve-cells. These fibers are found together in bundles, are covered with a kind of insulating sheath, and so forth, but essentially they are the projected portions of the protoplasm of nerve-cells, just like the projections thrown out by the amœba, or the cilia of ciliated cells. We now understand why the part of a divided nerve which is no longer continuous with the nerve-cells from which its fibers sprang must degenerate. Those fibers are really in just the same case as a piece of an amœba that has been cut away and is no longer sustained in health by the nucleus.

The processes of nerve-cells are of two kinds, and different cells vary widely in the number that they possess. The most important one is called an axone; and every nerve-cell that has not utterly degenerated must possess an axone, for by the axone alone does it give messages or orders.

A nerve-fiber not only conveys impulses, but has a life of its own

The majority of nerve-cells, perhaps, have only one axone. Some, called bipolar cells, appear to have two axones, one coming from either end of the cell, but only one of them is the axone.

But these cells, however, show, as a rule, a very large number of other processes, called "dendrites". These do not form nerves, and do not extend far from the cell they belong to. It is supposed that their function is to pick up impulses like the antennæ of a radio set. They are said to be withdrawn into the cell during rest or sleep, but we cannot be sure of this In advanced alcoholic or other poisoning of the cell, and also in senility, the dendrites degenerate in varying degree and may become broken up. This may be the consequence of the degeneration of the cell, or the cause of it — if the dendrons are the "feeders" of the cell. In brief, these dendrites convey impulses to the cell body itself which in turn transmits these impulses to other cells via the single axone.

But the details of the nervous system are for future study. Meanwhile, we must look at the properties of a nerve-fiber, now that we know its nature. It conveys what we call a nerve-current, or nervous impulse. Any given fiber can convey impulses in only one direction. In an ordinary "mixed nerve", such as we find in a limb, there are many fibers which proceed from motor nerve-cells, and many which proceed from, and convey impulses to, sensory nerve-cells. But each fiber obeys the law of its own nature, and the current in each fiber is undoubtedly insulated from all the others.

The details of structure of a nerve-fiber may be studied at length, and certain varieties of type may be identified. These differences are trifling; and the essential fact is that a nerve-fiber is a living thing, made of specialized living protoplasm, part of the body-protoplasm of the nerve-cell.

The function of the nerve depends upon its life. It may die, or be poisoned, and will convey nothing however it be stimulated and though its material continuity be unbroken. Nerves can be removed from a freshly killed animal and kept alive in "normal saline" or other fluids for a long time, and their behavior can be tested directly, and by observing their influence upon the attached muscle, if it be a motor-nerve that we are studying. We thus learn that a nerve-fiber is alive, and therefore behaves like living protoplasm. It is of simple type, however, and is almost inexhaustible by repeated stimulation — very unlike the cell from which it proceeds. When it is stimulated an electric current is always produced within it, and passes along it.

The nerve-current not electric, though electricity stimulates nerves

Naturally, we suspect that a nerve-current must be an electric current. This is not so. The nerve-current moves along the nerve not at the stupendous speed of electricity, but at rather rapid speed. In a frog's nerve it has been found to travel about 28 meters per second; in a human nerve the rate is estimated at about 120 meters per second. It is a change in the living protoplasm of the nerve-fiber, and it is instantly stopped when the stimulus ceases, so that the process can be at once and indefinitely repeated. There is no end to the possibilities of inquiry here, for all manner of drugs may be tried upon all manner of nerves in different animals; and we find that some substances excite motor-nerves, some excite sensory nerves, and electricity is a stimulus to all kinds of nerves. Cold lowers the excitability of nerves in warm-blooded animals, and moderate heat raises it.

When we trace nerves to their ends we find a variety of structures. The end of a motor-nerve is called an "end-plate", a kind of spreading out of the tiny fibers of the nerve so as to cover the greatest possible surface. The end of a sensory nerve may be a great variety of structures, according to whether we are studying touch or vision or smell, or what not. But a very large number of nerves, arising from cells within the central nervous system, never leave it. The axone of any nerve-cell of this kind travels a long way, perhaps from one side of the brain to the other, or from the brain to the spinal cord, or in many other directions.

Instead of ending in a muscle fiber or in some sensory organ, it breaks up and spreads itself out, and practically *embraces the body of some other nerve-cell.* We observe, then, that this vast collection of nerve-cells which we call the central nervous system is indeed a system, and not merely an aggregation. Nerve-cells not merely control other kinds of cells, but they control other nerve-cells. And when we survey the central nervous system from this point of view we reach a great new conception, which the world owes to the famous physician, Dr. Hughlings Jackson, who died in 1911, and after whom is named "Jacksonian epilepsy".

Dr. Jackson saw that the central nervous system is made up of various levels, essentially three in number, of which the lowest is the oldest in the history both of the race and of the individual, the middle level coming next, and the highest level last; and the middle level can largely control the lowest, while the highest can largely control the other two. Each level has its own characteristics, the lowest being concerned with the merely animal life of the body, the next with the simpler emotions and managements of the body, and the highest being the seat of the essential part of man. This great doctrine is now accepted everywhere; and with the statement of it our survey of the nervous system as a whole is complete Our next concern is to ascertain how this system behaves in practice

WRONG AND RIGHT EXERCISE

**Dangers and Advantages in Athletics—
How to Strengthen Without Injuring the Body**

TRUTHS AND FALLACIES ABOUT EXERCISE

THE evil results of over-athleticism in schoolboy and undergraduate days has so often been called to the attention of the public that it should now be thoroughly warned against these dangers. The necessary reaction against this long-continued excess is now beginning to be in evidence; and we may therefore confine ourselves almost entirely to the discussion of the science of the matter which, particularly, is of very high physiological interest.

In our present analysis and explanation of the evils of over-athleticism, we shall definitely divide them into two categories—physical and mental. It has already been argued that, for the philosophic hygienist, the influence of anything whatever upon the mind must be the final criterion. Yet even for those who do not admit so much, and who argue that not only the first, but also the last, need is "to be a fine animal", let it be noted what a very unsatisfactory kind of animal over-athleticism produces, quite apart from any injury to the mind. The methods of physical development which ruin the most essential parts of the physique, from the heart onwards, surely stand self-condemned. The truth is that even physical exercise requires to have brains put into it, unless its own ends are to be defeated.

Most of the voluntary muscles of man are almost daily becoming less important, as modern invention supersedes them. But certain of the involuntary muscles retain, and must always retain, their primeval importance. Of these, the foremost is the heart, far and away the most important muscle in the body.

The remarkable lack of brains in modern notions of exercise, so unlike those of the ancient Greeks, is nowhere better illustrated than in the pre-war drill regulations of the British army, wherein no end of trouble was devoted to enlarging the size of the soldiers' chests. A series of disastrous exercises was invented, which made the chest abnormally rigid in a state of sham expansion, which evolved very serious strain upon the heart. After many years, when many thousands of recruits had had their hearts damaged more or less permanently by this absurdity, the regulations were altered. But they remain as an admirable illustration of the wrong type of physical exercise.

The whole and only value of the chest is that it shall be mobile. Its value is not in its absolute dimensions, small or great, but in the difference between its maximum and its minimum dimensions—a difference which physiologists term the "vital capacity". As we get on in years, the chest always slowly but surely enlarges, owing to the gradual loss of the elasticity which should restore it to its smallest size in the course of each expiration. This ultimately leads to stagnation of air and blood in the lungs, and strain upon the heart.

But if this be the kind of evidence which we find when we study the young man, what shall be said of the evils of over-athleticism in the growing boy? Here, of course, the evidence is not merely similar but still more serious. In some of our modern girls' schools the great effort is to imitate boys in every particular, to play all boys' games, and play them hard, often without proper adaptation for the girl.

Inquiries show the cult of athletics in some of our boys' schools often has the most serious and lamentable physical results, even for lads who are certainly not overtaxed in any other way, who live in pure air, and have plenty of nourishing food. If this be so for boys, it must certainly be a still more serious risk for girls.

The fallacies of the popular proposition that change is rest

As always, a competitive system of this kind is judged by those who set the pace for the others, and can stand it. Naturally endowed with fine physique, they are regarded as splendid products and illustrations of the value of the system — which is not even true; and nothing is heard of the much larger number who, in the endeavor to keep up with these few, have been more or less seriously injured, often for life. A powerful and very necessary reaction has taken place against these excesses, which begin by denying the first fact of all life — that individuals vary in natural capacity and cannot be subjected to uniform treatment without injury to many.

It is a very evident and important truth that "change of occupation is rest", but it is a truth that requires more accurate analysis than it usually receives. It has been most egregiously worked to death in connection with athletics. Those in charge of the young of both sexes have worked on the assumption that brain-work and physical exercise are wholly independent. It has been seen that the boy who was tired out with books and figures was yet quite evidently fresh and fit for keen activity out of doors when he was released. We may freely grant that change of occupation is the best rest in such a case, for the sufficient reason that the muscles of accommodation in the eye, many parts of the brain, and certain groups of body muscles, formerly hard worked, now receive absolute rest. They alone were strained, and now they rest — the formula about change of occupation means no more, in such a case, than that very simple proposition.

But next we have proceeded to assume that our formula, which really means so very little, works in the other direction. After physical exercise, the young people are set to brain-work again; not only young people, indeed, for thousands of brain-workers have tried the same plan with themselves. But in point of fact it does not work at all. Especially does it fail when the physical exercise has been something in a gymnasium, under the direction of a stern disciplinarian.

That is an extreme case, but what we are stating is true, in its degree, of all cases where the physical exercise really involves any fatigue. The fact is that real physical exercise of any kind involves fatigue; and no sooner does the physiologist study fatigue than he learns that this is a bodily condition which has a definite physical basis, and directly bears upon the working of the brain.

Professor Angelo Mosso, of Turin, in his "Fatigue", showed that it has a physical, or rather chemical, basis, consisting of poisons or fatigue-toxins produced by muscles involved in the exercise, and conveyed by the circulation of the blood and the lymph to all parts of the body, including the brain. It can be shown that hard work of the legs tires the arms, simply by distributing to the arms a proportion of the fatigue-toxins produced in the exercised muscles of the legs. This, of course, would not be so if fatigue were merely exhaustion of nutriment or energy supply in the muscles. More recently, those who have followed Mosso have shown that what athletes call training is mainly, if not wholly, a method by which the body acquires, through exercise, an immunity against the fatigue-toxins, just as it acquires immunity against many drugs, and against the poisons produced by many forms of disease-microbes. That doubtless explains the fact that modern trainers, even before prohibition, absolutely interdicted alcohol to their charges, for the experiments of Metchnikoff show it interferes with production of immunity to forms of disease-poison, doubtless by its retarding influence upon the action of those ferments in the body which produce the anti-toxins or antidotes to the poisons; and a similar action no doubt is effected upon the response of the bodily chemistry to the formation of fatigue-toxins.

The reason why vigorous exercise impedes the working of the brain

This conception of fatigue as toxic, which is no longer a speculation, but a definite result of modern physiology, must never be forgotten when we deal with the problems of physical exercise, and we must beware of applying the theory that "a change of occupation is the best rest" without discrimination. After hard physical exercise the whole body needs rest, because it is being flooded with fatigue-toxins. Even digestive rest is required, for very often if a hearty meal be taken during severe fatigue, it is found that the digestive organs, which were not themselves involved in the exercise, nevertheless behave as if they were exhausted.

Brain-work, however hard and intense, involves the production of only very minute traces of chemical waste products, far too slight to effect any influence upon the motor apparatus. Hence, the familiar doctrine already quoted happens to be right when the transition is from brain-work to physical work, and wrong when the change is in the other direction. Already in the regimen of the young, these important physiological findings are being attended to, and wise adults will soon begin to attend to them on their own account. The work of young people must be so arranged that the severest forms of brain effort, above all the actual acquirement and digestion of new knowledge, shall be attempted *before* the chief physical exercise of the day, and not after it. The competitive idea in our present sports and physical exercises for young people of both sexes requires very severe pruning.

We are not here speaking of games, but of athletic exercises and competitions and displays. The risks, then, which are more conspicuous in such athletic exercises as long-distance running races for growing boys (whose sprints should never exceed, say, one hundred yards), may also extend even to quite desirable games if certain precautions are not taken. There is a definite risk in any game where girls are seriously urged to measure their physique against that of boys.

Conditions under which vigorous sports may become harmful

It is absurd that children of either sex, when playing grown-up games, should be expected to imitate the conditions which suit strong men in their middle or late twenties. If 60½ feet for the distance from the home-plate to the pitcher, and a certain number of ounces for the ball, are right for adult baseball players, it is egregious that a youngster of thirteen should be expected to pitch the same distance with a ball of the same weight. A lighter ball, not quite so tightly wound, and therefore not so hard, and a distance of even as little as forty-five or fifty feet for small boys, will improve the game for them and be much safer.

Similarly, in games like hockey and football, the periods of play should always be many minutes shorter than those prescribed for adults, and the area of the playing-field should be much smaller.

As regards the adult's regulation of his own exercise, medical men are only too familiar with the carelessness and strange lack of reason which so often bring disaster in their train, above all to the muscular tissue of the heart. If we define as violent exercise that which causes us to become "out of breath"—an intensity which, of course, varies with the individual—then we must further note that violent exercise, thus defined, always means that serious, though not necessarily excessive, demands are being made upon the muscular tissues of the right ventricle of the heart. It is always the right ventricle that bears the brunt of exercise, having large quantities of blood poured into it, and being required to force them, at a great pace, through the lungs for the oxygen which the tissues are so rapidly using up; and the wall of the right ventricle is relatively thin.

But not all exercise that makes us out of breath is to be avoided. So long as the ventricle, stretched by its efforts, will return to its normal size in a few hours, we need not fear, but the exercise which produces dilatation not so quickly and completely recovered from is very danger-

ous indeed. Tapping the chest, or throwing Röntgen rays through it, will demonstrate that, when a schoolboy, or even a trained athlete, runs a hard quarter of a mile, the right ventricle dilates, under the pressure within it, to such an extent as an inch or more; and it may often be twenty-four hours before it resumes its normal size.

There are two ways in which the heart responds to excessive exercise. In some cases it enlarges in response to the need, and certainly that "compensatory hypertrophy" is the best that it can do. But though such hypertrophy, in the case of an ordinary muscle, involves no risks, in the case of the heart it is a source of future danger, however necessary at the time.

The muscle that matters most and is the most ill-used

The blood-supply of the heart-wall is inexorably limited by the caliber of the arteries which supply it, and the last state of hypertrophy of the heart is inevitably fatty degeneration of the overgrown muscle. Sooner or later the fatty heart must yield to the pressure within it, for fat cannot contract, and is not elastic. In the second group of cases, the heart does not begin by making the response of hypertrophy to overexercise, but dilates at once, and remains dilated, and thus is necessarily inefficient in one way or another, for mechanical reasons.

Mere overstraining, or temporary overdevelopment, of the muscles of the limbs matters little, and even damage done to joints usually matters little more, but damage done to an organ like the heart is vitally important.

The knee-joint is liable to serious trouble from over-exercise. This is the largest and most complicated joint in the whole body, and very easily injured when it is subjected to certain forms of strain. Often it is the "internal semilunar cartilage" of the joint that becomes displaced, and in many instances nothing but surgical removal will relieve the patient's disability. True, natural movement of this joint, as in walking or running, is not to be feared, only oblique and sidelong strains such as occur in football and certain kinds of jumping. Anyone whose joints and bones are constructed lightly and delicately should avoid such risks.

Now, if the foregoing arguments and the doctrines discussed in the preceding chapter mean anything, they certainly unite in condemnation of the foolish "Cult of Muscle", with which we must now deal, for it is perhaps the best illustration of exercise of the wrong kind.

The muscle-making craze an exercise of the wrong kind

By the cult of muscle we mean simply the much-advertised craze which teaches, in effect, that there is nothing great in man but muscle; that to be a good animal is everything; and that we must develop every muscle to the utmost. No serious student of anatomy could listen to such nonsense, for the study of the muscular system of the human body shows at once that it has many and widely distributed survivals of organs and muscles, which have nothing to do with what are now the habits of man. They do not even serve him if he wishes to excel in games, for his games, as we shall see, are based upon the characteristics of skill and coordination, and not nearly so much upon the high development of any special muscles or groups of muscles.

But the cult of muscle, like cults in general, is highly profitable to its chief exploiters, who include some very enterprising and skilful men of business. The theory apparently is that, having defied for years together the most elementary and cardinal principles of ventilation, cleanliness, exercise and diet, you may make good the damage by physical training and enlargement of the muscles.

It is deplorable to find how many people accept the cult of muscle in this preposterous fashion. Whether or not a spiritual paradise may be won by a deathbed repentance after years of evil-doing, certainly a physical paradise is not to be won by a belated and disproportionate and spasmodic attention to one of the minor laws of health, after years have been spent in defiance of the primal and unescapable laws of man's physical being.

How science and our feeling of fitness alike condemn artificial exercise

Man's adaptation to his environment is chiefly nervous and mental. His body contains numerous and important "disharmonies" between his physical constitution and his present vital needs. The voluntary muscles are really the end-organs of certain kinds of nerves called motor, existing for the execution of *purposes*, and it follows that the muscles for which the nervous system and the will have no purpose are simply a burden.

This single consideration gives us a very useful, practical criterion at once. The modes of exercise which could not possibly effect any purpose, but simply contort the body, or practise one isolated part of it as if it were a machine, are self-condemned. Either they are developing muscles which are not worth having, or else they are effecting a disproportionate development of some part of the body at the expense of the rest, and of the purposes of the whole.

The demands that muscle-making imposes on the various vital organs

A muscle is a living organ of great inherent vitality. It consists of very active living protoplasm, highly unstable, and needing a generous measure of nutriment. A healthy muscle, in a state of "tone", is always consuming food and producing waste products, in proportion to its bulk. The highly muscular man, developed by one of the new "systems", requires much food, and throws a heavy burden upon his digestive and excretory organs. If muscles are to be maintained at their largest, they must be constantly exercised; and not only does this mean a higher demand upon the organs of digestion and excretion, but, as we have seen, it involves the poisoning of the brain, as well as the rest of the body, by the fatigue-products of muscular exertion. Thus the brain has to pay a double price for the devotion of the bodily resources to the muscles. Large meals involve a large blood-supply to the stomach and the rest of the alimentary canal.

The right relative positions of brain-work and physical exercise

This, again, always means the relative starvation of the brain, and shows itself, after a meal, in the torpid or sleepy condition of most large eaters, or of a smaller eater whose blood-supply is not quite adequate.

A considerable degree of relative starvation of the brain must therefore be added to the temporary and slight but very effective poisonings of it by fatigue-products in the case of the man who lives for his muscles.

The value of exercise is not at all that it makes us muscularly stronger, with the consequent necessity of having to devote a higher proportion of our vital energy to the muscular upkeep.

The familiar confusion between muscularity and vitality

It is valuable for other purposes; and in our discussion of the various right kinds of exercise we must keep those other purposes in view. Few who grumble at the necessity of taking exercise, or who simply decline to take the time for it, will realize that the special and sufficient reason why they need so much is that they persistently eat too much. So long as they do so, they must take much exercise, which, in part neutralizes the effects of their over-indulgence. That is obviously a reason and a function for exercise which should not exist.

And, again, it is a delusion that exercise, and high muscular development, make us resistant or "strong" in all directions. That is the old and familiar error of confounding muscularity with vitality. The two things are utterly different, as we realize when we compare the relative resistance of the two sexes to starvation, hemorrhage, poisoning or cold.

Further, "training" really means the acquirement of immunity to fatigue. But all immunity to toxins is specific; vaccination only protects against smallpox, not against mumps or chicken-pox, and so on. Similarly, one may become immune to the fatigue-toxin, but helpless before others.

The right kinds of exercise: why play in the open air is ideal

If we hold fast by the principles already enunciated, we can now make speedy and certain decisions as to the right kinds of exercise, the health and healthy stimulation of the brain and of whatever serves the brain, for ourselves and others at any age.

The simplest form of exercise is that obtained in any moving vehicle in the open air. To the gymnast or the oarsman, no doubt, such a use of the word "exercise" seems monstrous. But it has now been proved that even riding in a carriage, naturally much more in an automobile which moves so much more rapidly, does actually stretch the muscles by a reflex action exerted through the nerves of the skin. No doubt this exercise is inadequate, but if anyone doubts whether it really be exercise, let him undertake a first ride in a wheel-chair "along the board walk," after grippe or appendicitis, and have his ride just five minutes too long.

Reflex action of moving air on muscles

The truth is that experiments made in the laboratory on the action of moving air upon the skin, and thence by reflex action upon the muscles, the glands, the production of heat and the processes of secretion, have given all students new ideas of the importance of the skin and of cutaneous stimulation. They have shown that the most expensive and elaborate systems of ventilation, such as are often employed in public buildings, which produce a perfectly pure and motionless atmosphere, are the worst that can be devised. In such a "dead air," as it has well been named, our skins lose an indispensable necessity for real health, during every moment except when we are asleep — namely, the stimulation of tiny, incessant blows, striking us in all directions, and dealt us by little currents of air. We say that a man wants a pin run into him to wake him up. Just so does the nervous system require the incessant tiny pricks of shafts of air if it is to work properly. Here, at last, is the kindest explanation of the "sleepy feeling" in church.

Supineness in the open air better than exercise in an indoor gymnasium

All this means that the various forms of exercise which consist, apparently, of no more than passive and effortless exposure to moving air — whether it moves past us, or we move through it, is, of course, immaterial — are being rehabilitated in the estimation of hygienists. And it is a clinching argument against indoor gymnasium work as compared to outdoor exercise.

Undoubtedly one of the valuable results of exercise is its promotion of full breathing, but deep breathing can really be of very little value unless it be the breathing of pure air. Indeed, if one had to choose between exercise in the ordinary indoor atmosphere and lying supine in the open air, it would be wise to choose the latter. Every indoor gymnasium, every system of developers and exercisers, is to be condemned if it keeps people indoors. There is no comparison, on the score of health, between the most elaborate and carefully thought-out system of indoor exercise, however complicated the apparatus and certificated the teachers, and the most informal stroll or scamper out of doors.

The value of a purpose beyond exercise while taking exercise

All exercise for the sake of exercise is a mistake — or, at any rate, a second-best. You may do your mind, and body too, more harm by sheer boredom than you may gain good from the exercise you go through. The dumb-bell is misnamed, for it shouts aloud the fact that the most elementary and obvious truths of psychology are still unrecognized, though the play and games of every natural child — if you object to being instructed by kittens — should be quite enough to teach us what, indeed, nature taught us ages ago, if only we would listen to her.

Everyone knows the difference it makes to have "an object" when one goes for a walk; and this universal and natural fact teaches us that we are not meant or constructed to take exercise for itself, but only to take it incidentally, without think-

ing about it, on the way to some end. The half-back who makes a touch-down benefits by the running, just because he is not running for running's sake, but to carry the ball over the line and help his side to win. In the new methods of therapeutic exercise for consumption, which are now in vogue at all sanatoria, the rule is to give the patients a piece of constructive work to do, with an end to aim at, and the fruit of their labors visible in front of them.

The best exercise, other things being equal, is the one we like the best

And so doctors are abandoning the indiscriminate ordering of mere "constitutionals" as such; they know more about the human constitution now. Walking is an inadequate exercise, in itself, for the reduction of weight in cases of obesity; and many walkers for their figures' sake have been disappointed in this respect. The great hygienic virtue of golf, so popular a game of many, is that they *find* it a game; and just because they have an object, they undertake the walking first, and the exposure to the open air second, which do them so much good.

The truth is that the best exercise, other things being equal, is that which we most enjoy, for happiness is the best tonic. Thus, though it is possible to generalize about the best exercise on the assumption that man is a machine, on any other assumption we must find out in the individual case what is enjoyed. But the enjoyment must be natural, and compatible with open air. Also, we must condemn all forms of exercise, whether or not the individual happens to enjoy them, which interfere with breathing. This entirely condemns weight-lifting and short races, where the runners are taught not to breathe at all during, say, a hundred yards sprint. The lungs are inflated, fixed, and only deflated when the race is over. This undoubtedly makes for speed, but it is exceedingly bad for the heart. The latest device is the inhalation of oxygen gas from a cylinder before the race, so that the expert may hope to be able to run even a quarter of a mile without deflating the chest, say in fifty seconds or less.

All this is vicious, and must be condemned without reserve. These are the kinds of practices which result in permanent dilatation of the heart, stretching and bursting of the ultimate air-cells in the lungs, and the allied evils which have led to the round condemnation of all spectacular, competitive sports by some extremists. To interfere with breathing is bad in itself, and it is bad for the heart, which largely depends for its health and its proper functioning upon the help it derives from the movement of the lungs.

But in health, for young and middle-aged and elderly, there is nothing like play. That is the verdict of modern physiology and psychology alike. Health and joy come from the attainment of skill, not of strength; skill, which is man's characteristic, rather than the animal strength which his skill has superseded and masters. In games we exercise not merely the muscles, but the senses; they are therefore educational for young people, in the profound sense, as other forms of "physical education", so called, are not. And the value of a purposeful movement made in a game is of a wholly different order from that of a not dissimilar movement which may exercise just the same muscles, for it involves the training of the neuro-muscular apparatus as an instrument of the will.

Much might equally be said as to the moral education, in discipline, self-control, judgment, unselfishness, honesty and so on, that are required in the finest playing of the finest games, but this will suffice. There are worse mottoes, for hygiene and for work, for life and for death, than "To play the game".

Athletic sports in America: are they or are they not overdone?

There has always been considerable discussion in this country, favorable and unfavorable, in regard to violent athletic sports, one group taking the stand that they are harmful, being a strain upon the heart; another group being equally insistent that they are beneficial and build up a sound physique.

Which of these is right? Neither is wholly so. It all depends upon the type of sport, the circumstances under which it is conducted, the physical condition of the individual, and his attitude of mind. Most harm has come, when any has resulted, from lack of training or over-indulgence. In the United States, for example, most injuries in football have occurred among high and preparatory school boys who have not been properly conditioned. Injury has resulted, not so much from the severity of the game itself, as from the condition of the player. Persistence in playing when not in good physical condition is the chief cause of trouble. Then, too, many young men participate in too many games demanding great exertion within too short a period. There are not sufficient rest intervals, and the strain upon heart and nerves is therefore too great.

The psychological element in the question of relative good or harm of sports

The psychological element is a very large factor in the question of the relative good or harm of sports. If a man engages in athletic games simply for the fun there is in them, and not primarily to win a victory or for a prize, it is usually most beneficial for his health. If, in competition for victory and for a prize, he trains under good advice for the contest and participates in it not too continuously, with a wholesome attitude of mind toward winning or losing, it should also be to his general physical advantage. But if the desire to win is exaggerated, if there is over-indulgence and lack of proper preparation, the results may prove disastrous An athlete should never compete when not in condition Overtraining is as bad as undertraining

Biologically speaking athletics sports *per se*, those involving running, jumping, throwing and climbing, are most beneficial. They use the different parts of the body according to their natural functions. This is not so true of gymnastics The latter includes the use, frequently, of parts of the body in positions that are not so in accord, as, for example, supporting the weight of the body with the arms or hang ing by the toes. The arms were not made to support the body and when they are used in this capacity frequently, the shoulder joints become restricted in movement, like the hip joint. Gymnasts often become "muscle bound". Games and plays involving natural movements are always the best.

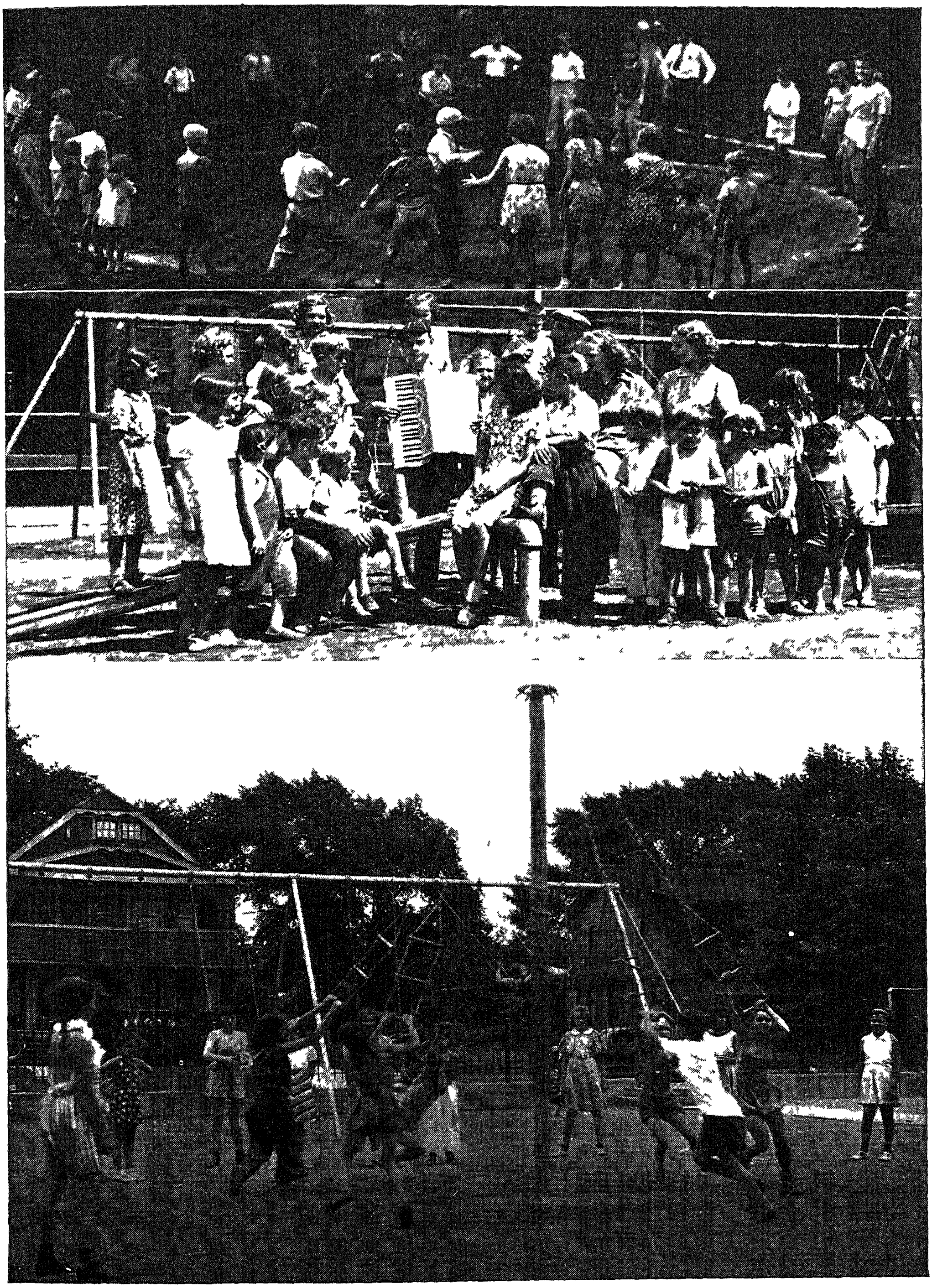
Another advantage of athletic sports is their tremendous interest. They have a rich psychic content To run, to jump, to strike, to throw, to climb, are absorbing pastimes These activities make up most of our popular sports, like baseball, football, basketball and lawn tennis. They are movements which are as old as the life of the race. They have associated with them memories, perhaps unconscious, of the chase and the hunt. One loves to do them and for that very reason is often tempted to overdo them. One can go through calisthenics and gymnastics without excitement, but how different it is with sports and games!

The elements which, from a physiological standpoint, make the best games

From a physiological point of view, the best games are those which have:

First, the element of interest. There must be an emotional appeal. We engage in them because they are enjoyable. They must have enough variety in possible number of plays to appeal to the imagination and to the wits. This is the charm of baseball, lawn tennis and golf. We never know just what to expect. Each game has its surprises. If enough, the game becomes absorbing. We forget our worries. It relieves nervous fatigue. It proves stimulating.

Second, the element of competition. A match challenges to extra effort. If one can measure one's performance against a competitor, it adds to the exhilaration which comes from such exertion. Simply to go through physical movements without some such stimulus as is given by mild competition will not cause the muscles to contract so vigorously nor induce the exertion that is organically most beneficial.



Playground Activities in Cleveland, Ohio

Top, group playing touch ball, Buhrer playground; center, singing club group assembled around the accordion player, Waring playground; lower, activity on the giant stride, Robert Fulton playground.

Third, the element of variety of muscular exercise without prolonged strain and with frequent intermissions. This is highly important. Exercises of prolonged strain are dangerous. They increase blood pressure and produce muscle strain and temporarily interfere with breathing. Note how in weight-lifting the athlete's eyeballs bulge, his veins enlarge, his face flushes, his whole body is in a position of continuous strain. The safest type of sport is that which demands but momentary strain or effort, which calls for a wide variety of muscular movements and with intervals of rest. Take tennis, for example. Play is usually rapid, the movements sharp and quick, and separated by the longer intervals of picking up the balls and getting ready for the next serve.

Short dashes, like the 100-, 200- and 400-yard sprinting events, are good illustrations of athletic exercises which demand a tremendous expenditure of nervous and muscular energy. Fortunately, the duration is brief or the result would be exceedingly harmful. Long-distance running races, while tests of endurance, are not tests of strain like short dashes, except at the finish. They begin more or less leisurely. Strength is measured in advance and the pace set accordingly. A long-distance race is not, as a rule, as nerve exhausting as a short one.

If one were to attempt a classification of games with reference to their effects upon the nervous system and their physiologic value, we should find them ranking about as follows:

Courtesy Canadian Pacific Railway

SKIING OFFERS THRILLS FOR THE EXPERT AND SPILLS FOR THE NOVICE

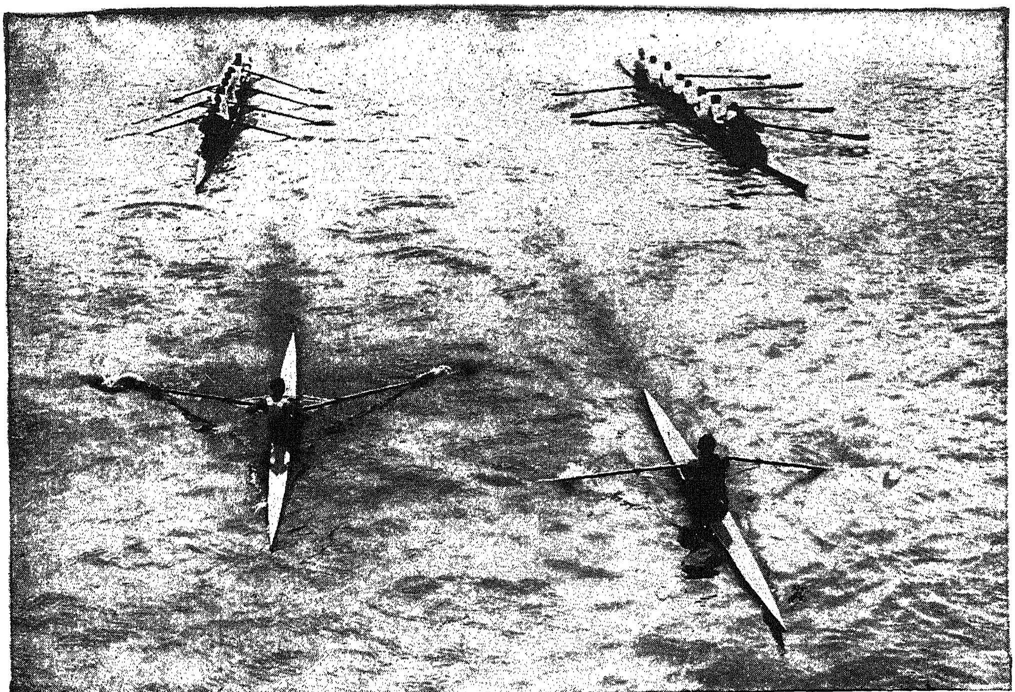
Now these waits between are very important, physiologically, because they ease the strain and provide a period of brief rest. So, too, in golf, the time spent in looking for a lost ball is not lost time. In American Rugby football, the game is kept from being too severe by these same pauses while getting ready for the next play. In fact, the time spent in preparation probably exceeds that of actual play. A game of basketball may become a very severe test if the referee does not interrupt it by frequent calls of fouls. Vigorous, sustained play may be too long in duration. One of the valuable features of baseball is the recurrence of the innings, which provides for rhythmic periods of play and rest.

1. *Games and sports which are mildly stimulating:*

Throwing and catching a ball informally. Tossing a medicine ball from different positions. Pitching quoits. Archery. Target shooting. Bowling. Bowling on the green. Walking.

2. *Games that are vigorous but without nerve strain:*

Volley ball. Informal tennis. Non-competitive baseball. Cricket. Punting football. Riding. Noncompetitive running, jumping and weight throwing. Golf played without over-regard for winning. Boxing lightly for points. Tag games. Circle games. Hiking and walking at vigorous pace.



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SPEED PRODUCED SOLELY BY THE MUSCULAR ENERGY OF MAN — A RACE FOR THE WORLD'S SINGLE SCULL CHAMPIONSHIP

3. *Games that are vigorous and require special training:*

Competitive baseball, basketball, volley ball (in tournament games), cricket, lacrosse, hockey, polo, soccer, cross-country running, track and field sports, walking contests and long hikes.

4. *Games containing an element of strain and requiring endurance:*

Highly competitive basketball, football, lacrosse, hockey, boxing, wrestling.

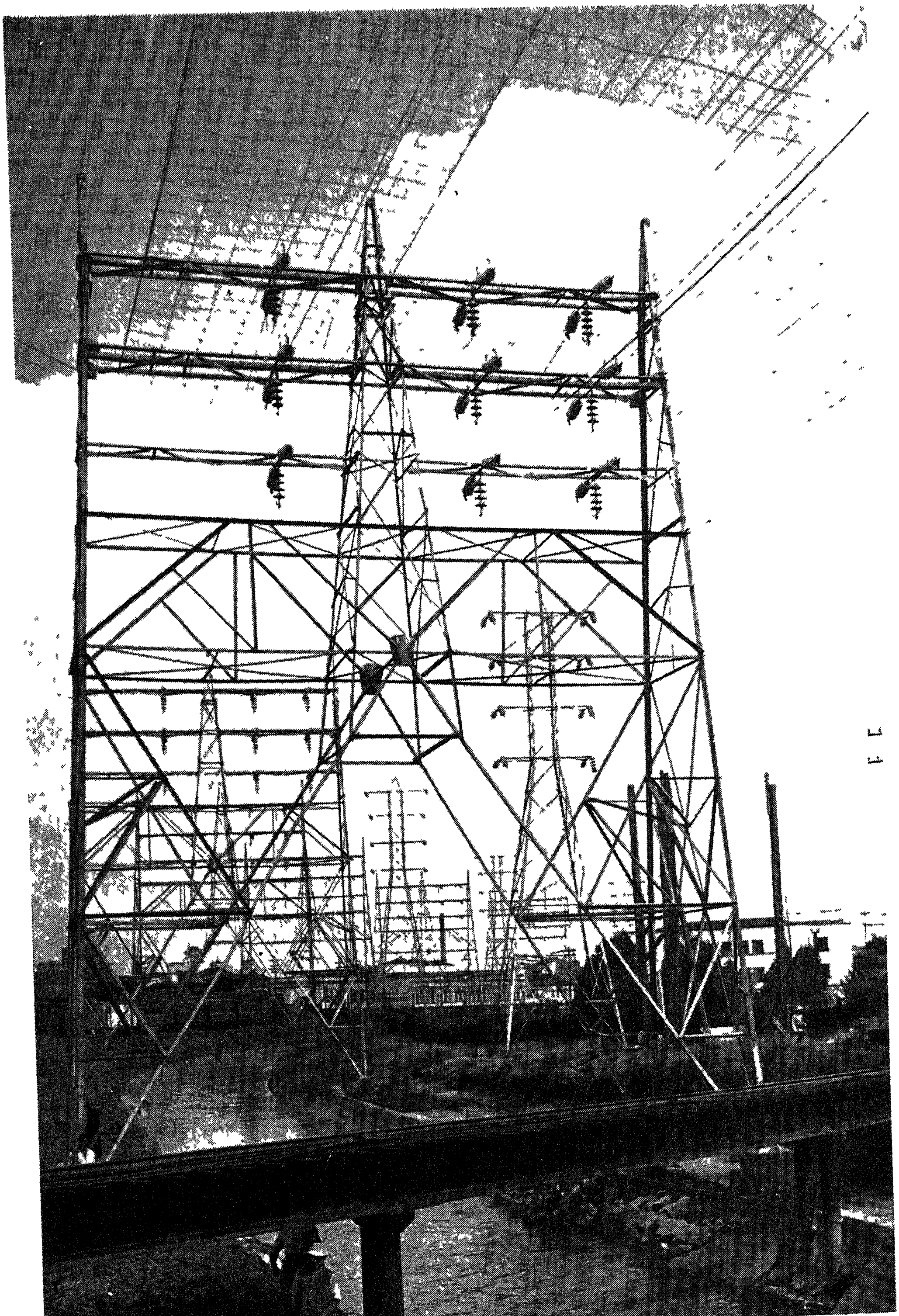
5. *Games that are dangerous:*

We should place among the dangerous sports boxing, wrestling and football. Only those in excellent physical condition and who have no physical or organic weakness of any kind should participate in any of these sports. Boxing is dangerous because a blow may be received at any time on a vulnerable spot and, in the latter part of a contest which is allowed to go beyond eight rounds, the participants may be so fatigued as to be peculiarly susceptible to injury. World champions sometimes find fifteen rounds to be too much.

Wrestling is a particularly dangerous game. It violates all the principles of wholesome exercise. The exercises are those of sustained strain and tension long drawn out. Wrestlers develop thick necks and big muscles and correspondingly large hearts. Young men should take up this form of exercise very cautiously and under competent advice.

Football is a dangerous sport because of the constant bodily contact, the tackling of the player when running at top speed, and the mass plays. The game has been opened up considerably and made much safer, but there is, because of the very nature of the game, likelihood of injury. It is not a game for boys of preparatory or high-school age unless they are thoroughly conditioned and provided with full equipment.

There is not supposed to be any violent contact in basketball; such contact is penalized. But the feverish pace at which the game is played often puts a severe strain on the hearts of the players.



Pan American Airways

Electrical energy is transmitted from the power station to the consumer over these transmission lines.

TRANSMISSION OF POWER

An Interesting Chapter in the Story of Industry

THE evolution of power transmission constitutes one of the most fascinating chapters in the story of industrial growth. Early man applied the power of his muscles directly to hand tools like hammers or chisels; he also harnessed the power of animals, such as oxen and donkeys, to help him perform certain tasks. A notable advance took place when the power that was supplied by wind or by running water was transmitted by means of wooden shafts and cog wheels to the stones of mills.

When the steam engine was invented in the eighteenth century, a new and truly formidable source of power became available to mankind. It was transmitted through a complicated system of shafts and belts and pulleys. As time went on, engines grew in size and became more efficient; longer belts were provided. If a factory happened to be exceptionally large, more than one engine was installed, so that it was no longer necessary to extend the system of shafts and belts to inconvenient distances. Yet even the most efficient steam-powered factory was only a sort of mill on a large scale; for power could not be transmitted beyond the factory walls.

Electric power comes to the fore

Up to a comparatively few decades ago practically all factories utilized steam power, generated on the premises and transmitted to the various machines by the complicated system of shafts and pulleys and belts. Then a revolutionary change took place. Men succeeded in harnessing the flow of electrons along a conductor and in transmitting the power supplied in this way over distances, not of a few hundred yards, but of many miles. (See the article The Nature of Electricity, in Volume 1.) This newfangled electric power could be generated in dynamos run by the force of steam or running water. Current could be transmitted to factories far removed from the place where it was generated. It supplied power to run the innumerable machines utilized by modern industry; it furnished light; it made available the electricity required for industrial processes like the synthesis of ammonia or the winning of aluminum from its ores. Today electric power has acquired a dominant position in the world of industry. Some day, perhaps, it may be challenged by the energy released from the core of the atom (see the article Atomic Energy, in Volume 4); but, as far as we can see, that day is pretty distant

Power losses in plants run by steam

The great objection to the shaft, pulley and belt system of transmission has always been the enormous proportion of power lost in friction. In the average factory powered by steam, it was estimated that for every horse-power that was provided by the engine, less than half a horse-power was available at the machines. More than half was lost on its way, in the rubbing of the shaft journals, the clinging of the belts and the sliding of the teeth of the gears. If these mechanisms were poorly adjusted, power losses in transmission were even greater. Even in cotton factories, which were among the most efficient of steam-powered factories, power losses were considerable—40 per cent in some cases.

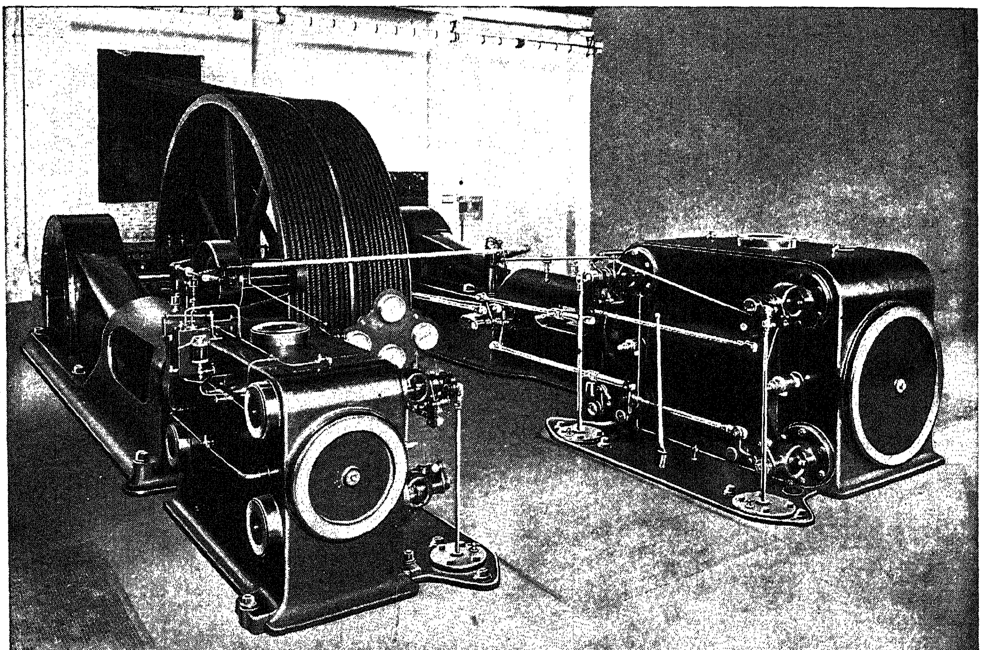
If power is transmitted directly to machines from a generator of electricity through a system of electric wires, instead of through shafts, pulleys and belts, the power loss is not nearly so great. It amounts to only about 10 per cent of the total energy produced by the generator.

Let us glance at the sources of power which are commonly harnessed into service, and consider them from the point of view of their value as agents for transmission. These are steam, gas, oil, water-pressure, air and electricity.

Steam — a mighty storage of energy that has formed an exhaustless theme for so many pens in the past — is being rudely shouldered out of spheres where formerly it was unchallenged. The reason is that you cannot transmit steam more than a few hundred feet in pipes without the loss of much of its energy by the dissipation of its heat. Therefore, the steam generator — the boiler — must be near the engine, and the power given out by the latter transmitted by other agents: until recently shafting and pulleys, connected by leather belting, ropes or toothed wheels. With relays of these agents a very large factory can be served from one set of engines, but with a sacrifice of, roughly, one-half the power of the engine, lost in the friction of the transmitting elements.

Gas carries the problem of power transmission a stage in advance, because gas can be conveyed in pipes over distances measured by miles. But the gas must be cheap to compete with steam, and therefore city gas cannot enter into rivalry with steam. Only waste gas from furnaces or gas generated in producers from cheap fuel can sustain that rivalry. The field of transmission is extended, but only with a rather limited area.

Oil occupies much the same position as gas, because it can be conveyed in pipe-lines and stored for use. But neither it nor gas can help the problem of transmission very much, because in both cases the engine which transforms the latent energy of the gas or oil into active force is located, like the steam engine, in one spot, from which the power must be distributed by other means. A steam engine, or a gas or oil engine, can only do work directly over long distances by being attached to a vehicle, which is a development of a different character from that which we are considering.



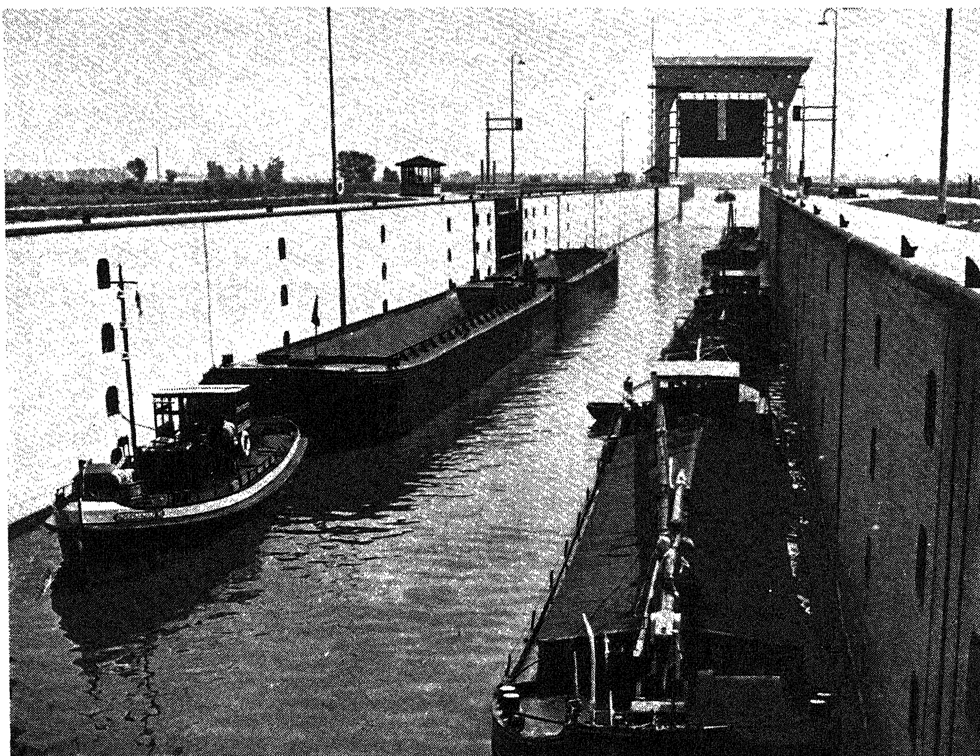
Courtesy Providence Engineering Corporation

RUNNING A MILL BY MEANS OF A ROPE DRIVE

This is a 900-H. P. Rice and Sargent horizontal cross compound steam engine. The boiler pressure steam first enters the nearer high pressure cylinder. The expansion begun here is then completed in the larger low pressure cylinder. From there the steam passes to the condenser which makes it ready to enter the boiler again as feed water.

Akin to steam, gas and oil engines are turbine water wheels, driven by the pressure and momentum of water falling from a height. (The pressure exerted in this case is called head.) Turbines differ from the old water wheels in being more efficient — that is, they make available a larger proportion of the power latent in falling water than the old water wheels did. The latter were employed to drive wheels, shafting and so on in the immediate vicinity. If electric generators had not been developed, turbines would probably have been utilized to transmit power by means of shafting, pulleys and ropes or belts, in countries where water power was plentiful and coal expensive. But as a matter of fact, the turbine has been used almost exclusively to generate electricity, which in turn drives machines, supplies heat and light and performs numberless other tasks for mankind. In this case, of course, water is only indirectly a source of power; the direct source is electricity.

Power, however, can be transmitted by water pressure alone, with practically no loss, since water is nearly incompressible. Pascal's law, concerning the pressure of a liquid that is completely confined, applies in this case. This law states that pressure that is exerted anywhere on a confined liquid is transmitted undiminished to every part of the containing vessel or pipe.



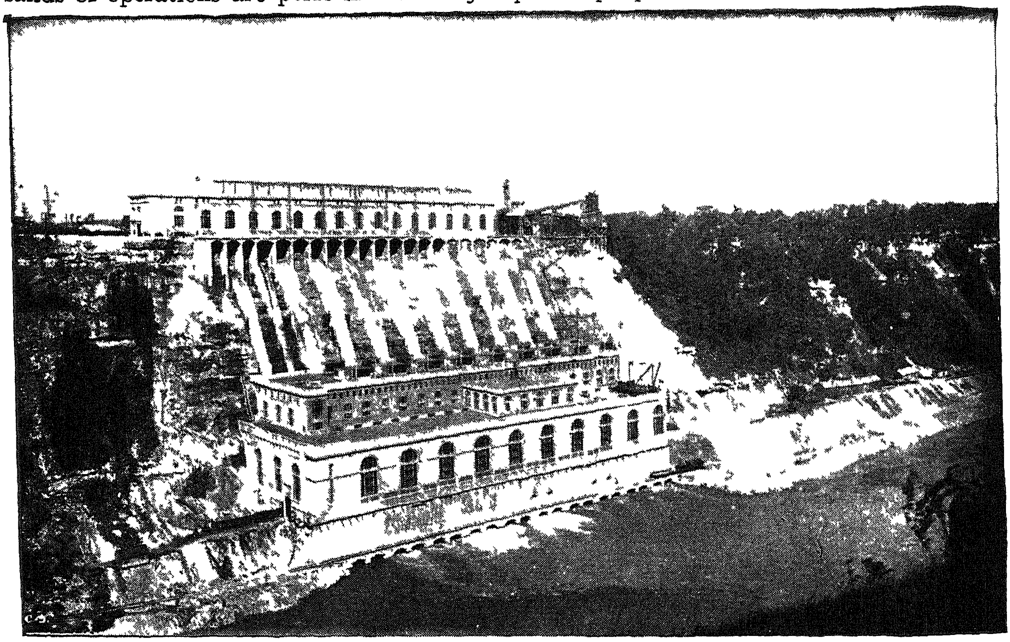
Netherlands Information Service

The Prince Bernhard Locks at Tiel, the entrance to the Amsterdam-Rhine Canal. Filling and emptying of the lock chambers is regulated by slides in the gates; each slide is worked by an electric motor.

Thus a pressure of one pound per square inch upon the small piston of a hydraulic press is transmitted by the liquid in this press to each square inch of a larger piston. In this manner a tremendous force can be exerted with surprisingly little effort.

Water pressure can be transmitted over quite long distances. When under high pressure water acts like a solid rod of steel, and pipes have to be very strong to carry it.

Though water-pressure can be conveyed thus for several miles, it is more often employed for lesser distances. It is used to transmit power to machines in workshops, and to cranes on quay walls. Most of the coaling of vessels is done by hydraulic cranes, worked by water conveyed in pipes. All steel ingots for guns and armor-plates are compressed by water-power, transmitted through pipes from pumps and accumulators. Every day, in every great center of industry and manufacture, thousands of operations are performed silently means of which a large quantity of impure water under a low head may be used to pump a smaller quantity of pure water against a higher pressure. Allied to hydraulic supply is that of compressed air. Conveyed through flexible pipes, it is much used for driving engineers' tools of various kinds. Many of these uses are in structural construction and underground work. Air under high pressure is carried for long distances, sometimes several miles, especially in mines and tunnels for both power purposes and ventilation.

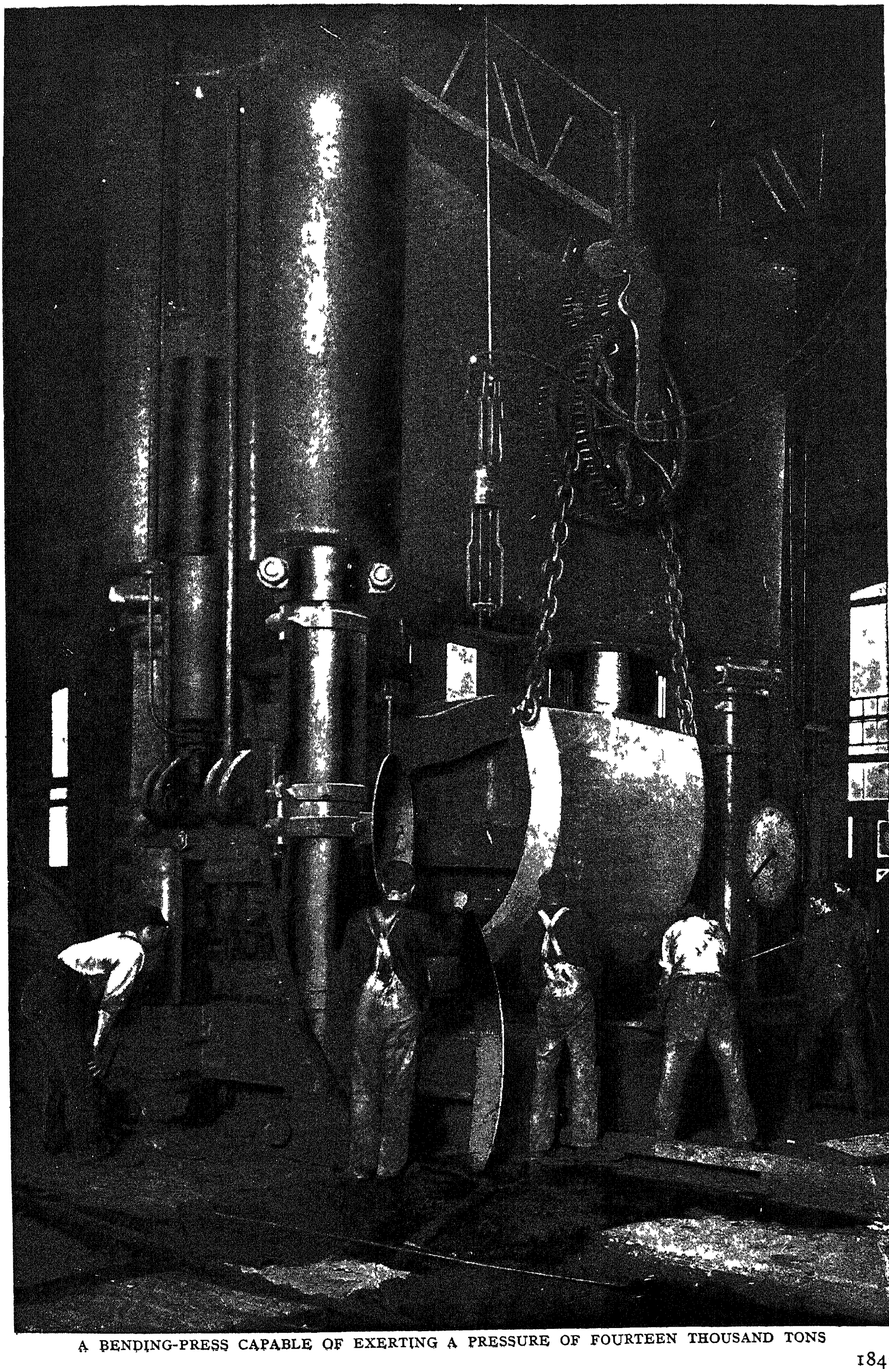


QUEENSTON DEVELOPMENT, NIAGARA RIVER, ONTARIO

Operated by the Hydro Electric Power Commission of Ontario, this plant has an installed capacity of 560,000 h. p. A carefully designed intake diverts Niagara water with the minimum loss of head. This intake is at the mouth of the Welland River, the current in which has been reversed, and the bed dredged to provide the necessary cross section. The average operating head at the plant is 305 feet and the average difference in water elevation at the intake and tailrace is 327 feet, so that the loss of head entailed in bringing the water 13 miles through river and canal is only 22 feet.

by massive machines actuated by water under pressures ranging from 750 pounds to four tons to the square inch. The heaviest engineer's work is done by this agent. A press at the Bethlehem Works in Pennsylvania exercises a total squeeze of 14,000 tons. Big dock-gates are opened and closed by water-power; swinging and lifting bridges, also, and much beside. Canal-lifts in England and on the Continent are worked by water-pressure, raising the barges from one level to another. An ingenious machine for moving water on a small scale is the hydraulic ram, by

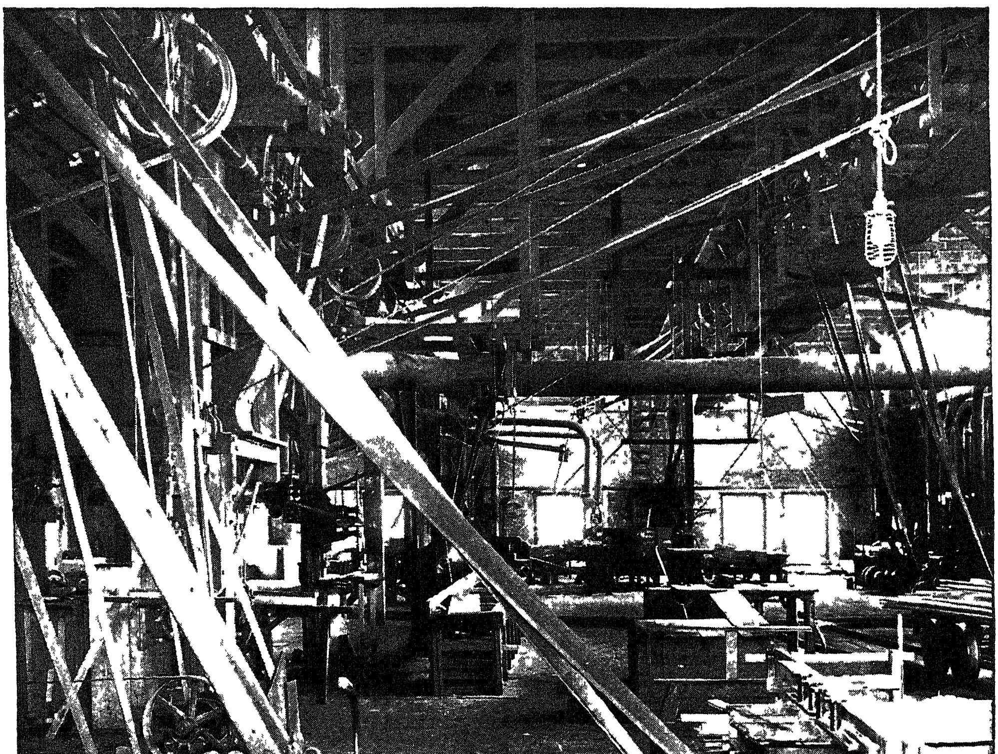
But electricity transmitted along stationary wires is the latest, and now by far the most valuable, agent of transmission. Its range vastly exceeds that of any other. It is a more flexible agent; and what renders it especially serviceable is the fact that every one of the power agencies which we have mentioned is readily convertible into electric energy on a rotating shaft. Electrical transmission has played a most important part in the development of water-power. Many such resources now available would be useless without long distance electric transmission.



A BENDING-PRESS CAPABLE OF EXERTING A PRESSURE OF FOURTEEN THOUSAND TONS

Mechanical difficulties in the translation of either form of power into electricity can be surmounted; the only question that remains for engineers is an economical one — that of the relative cost of different systems. Local conditions largely determine the selection. In places where coal is cheap, steam engines usually have the preference, but large gas engines are better in the neighborhood of great power-stations that utilize waste gases from blast-furnaces and other sources. In Switzerland, southern Germany, France, Sweden, California and Canada, the water-turbine is supreme.

Often the features of transmission to a factory or mill are reproduced within its walls. Then, instead of belts and pulleys and shafts, each machine has its own electric motor, driven by a cable from the main dynamo. But only in regard to the more recently equipped factories would this statement hold good. In many factories, shafts and belts, etc., have been reduced in number and their place taken by electric cables. Sometimes wholly replaced, but more often greatly lessened, small groups of machines are still belt-driven, but each group derives power from one electric motor. In practically all of the recently built factories, however, the full electric drive has been installed using the "one machine, one motor principle". Cranes, however, are an exception to this. A form of transmission of power akin to that of street railways and railroads is applied to electric traveling cranes, which may either run along on surface rails or on overhead tracks. Cranes of the latter kind will lift loads ranging from one ton to 150 tons by current conveyed along bare copper wires from any distance. These are located along the sides of the shop, and along the girders which carry the lifting apparatus — wires of three-eighths of an inch, or half an inch diameter only, yet charged with such enormous and helpful capacity!



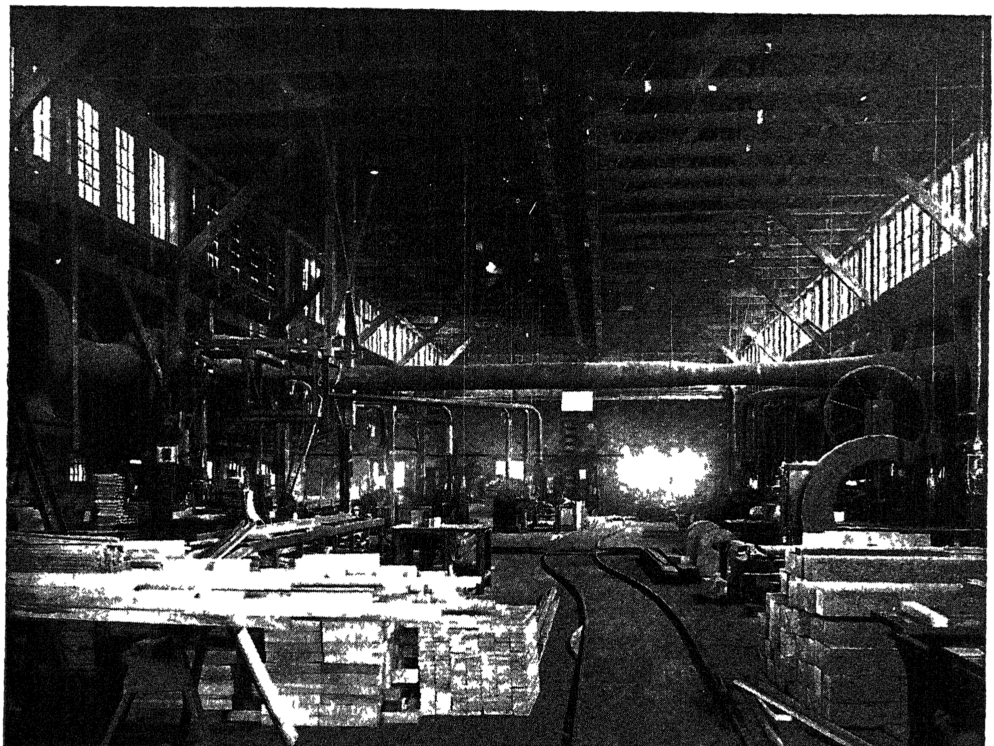
Courtesy General Electric Company

WOOD-WORKING FACTORY DRIVEN BY SHAFTS AND BELTS

The real era of long distance transmission began in 1893, when electricity, generated by water-power in Sweden, was sent ten miles, from the Hellsjon Falls to the Grängesberg iron mines The plant of this significant experiment was of 400 horse-power capacity, and it is still in successful operation.

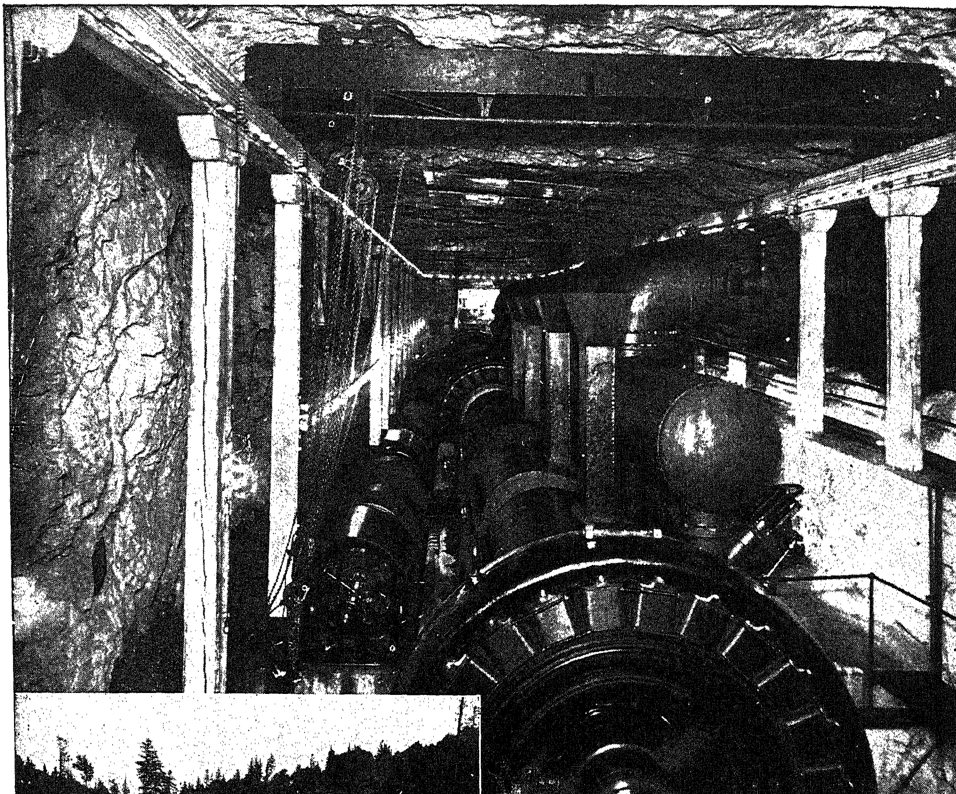
The hydro-electric power installations of Norway and Switzerland are numerous and wonderful, but those of California and the Pacific Coast generally are on a far vaster scale, and have been carried out in the face of greater difficulties by pioneers working in dense mountain forests where the ax has had to clear the way for the transmission wires. It is in these western wilds that the problems of very long distance transmission were solved, for San Francisco first, and afterward for other cities. Torrents there are in abundance all along the slopes of the Rockies. Cataracts and swift streams had run to waste since first the morning stars sang together, but many of these waters have now been harnessed to the service of man, and transmuted into light and movement. Always the agent is the cataract or stream, turning a turbine wheel, rotating a dynamo, and generating electricity, which the wires convey to the distant towns and cities.

Among the most remarkable of the installations in the West are the Snoqualmie Falls, in Washington, with a transmission of 83 miles; the Bay Counties of California, with 152 miles; and the Standard Electric Company, 154 miles. A part of the last used in connection with the Bay Counties has a transmission of over 220 miles. Startling and eerie are some of these installations. The Snoqualmie Falls are approached over a railroad that winds picturesquely up into the Cascade Mountains to the town, nestling in a setting of forest and gorge, and lighted by the waterfall. Here one must descend 270 feet below the surface in an elevator to reach the power-house, located in a cavern in the



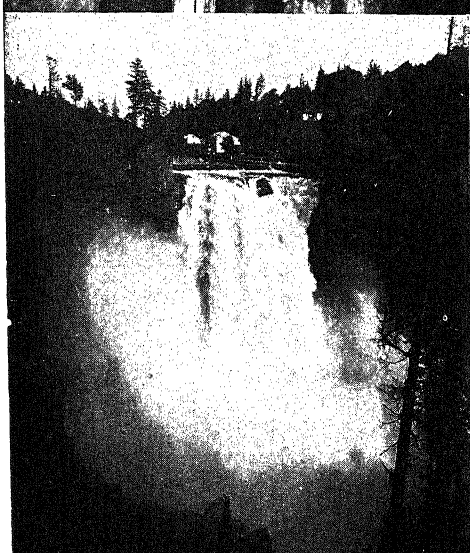
Courtesy General Electric Company

THE SAME FACTORY AFTER INSTALLATION OF ELECTRIC DRIVE



GENERATING STATION OF THE PUGET SOUND POWER & LIGHT CO.

Blasted and hewn out of the solid rock 270 feet below the upper level of the Snoqualmie River; a unique engineering feat.



© Asahel Curtis

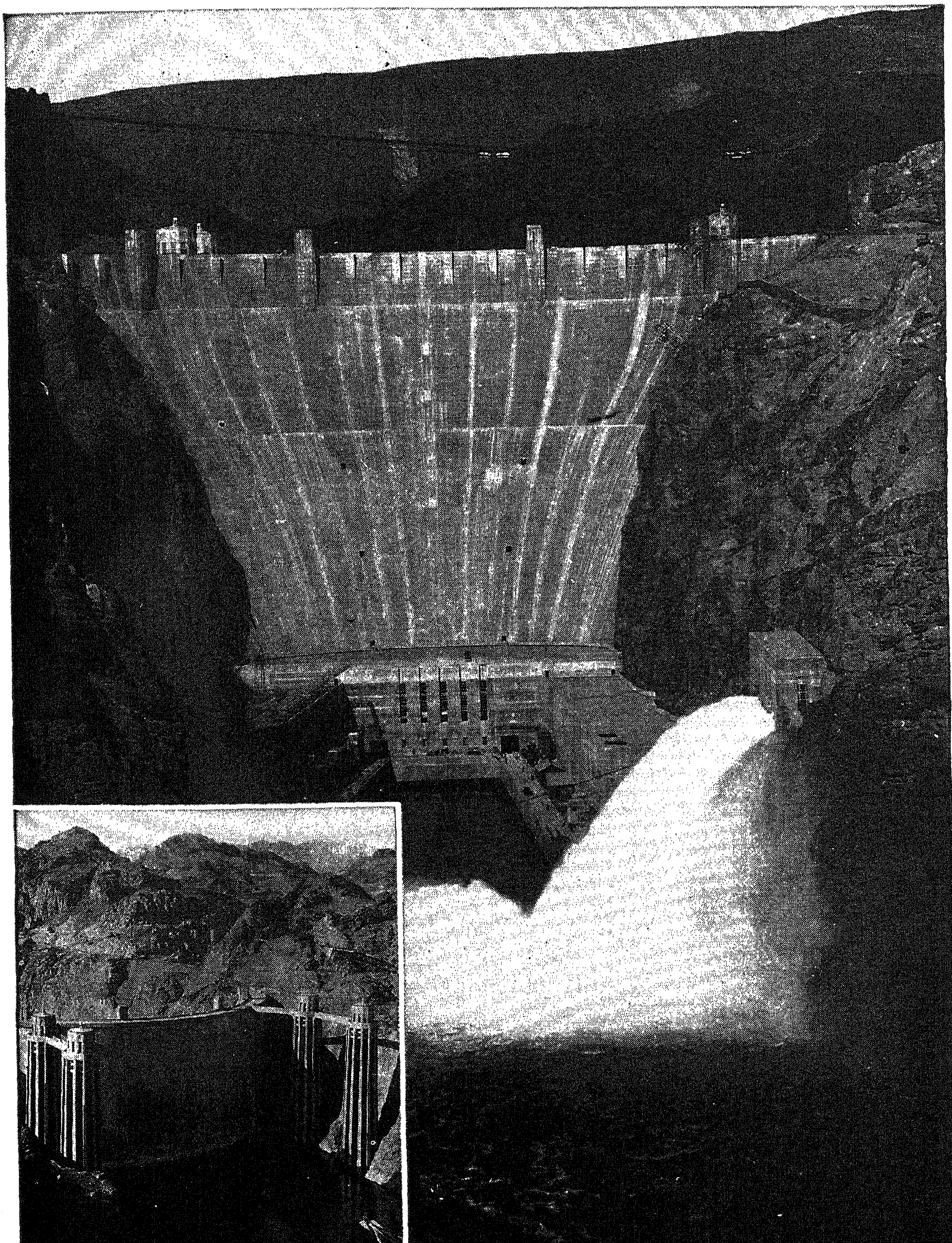
SNOQUALMIE FALLS

These falls, near Seattle, are 270 feet in height, or more than 100 feet higher than Niagara.

solid granite rock beneath the falls. In this cavern are six electric generating machines, and they are so placed as to afford protection to the machines from the everlasting spray from the cataract. Current is thence carried through dense forests of spruce and fir, a broad band having been cleared by the pioneers in order to prevent risk of trees falling on the wires and interrupting the service. This plant provides light and power for half a million people in two of the great cities of the Northwest — Seattle and Tacoma.

In transmitting power over long distances high voltages are used to eliminate unduly large losses through heat which would take place were the amperage not reduced. Such high voltages, though more efficient, tend to find out the weak spots of a transmission system, and then trouble occurs. This is the reason why progress has been tentative, and apparently slow. Now some electricians confidently anticipate voltages exceeding 200,000 transmitted over distances of more than 400 miles — and this is not unreasonable.

CHANGING WATER CURRENT INTO ELECTRIC CURRENT

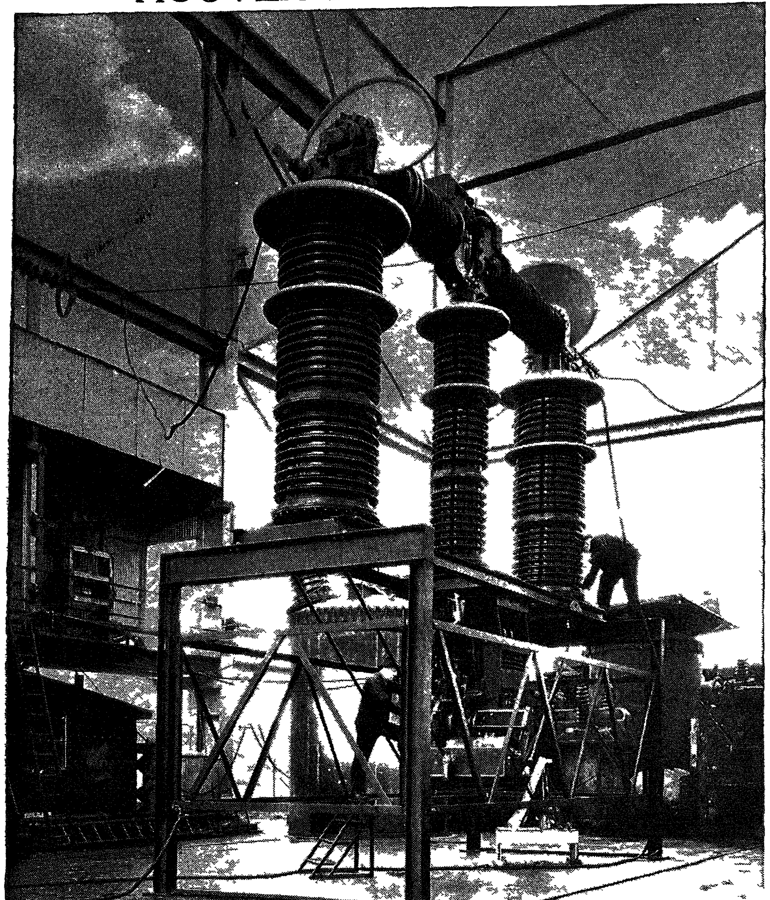


Courtesy U. S. Bureau of Reclamation

HOOVER DAM WITH THE ARIZONA WALL OUTLET VALVES OPEN

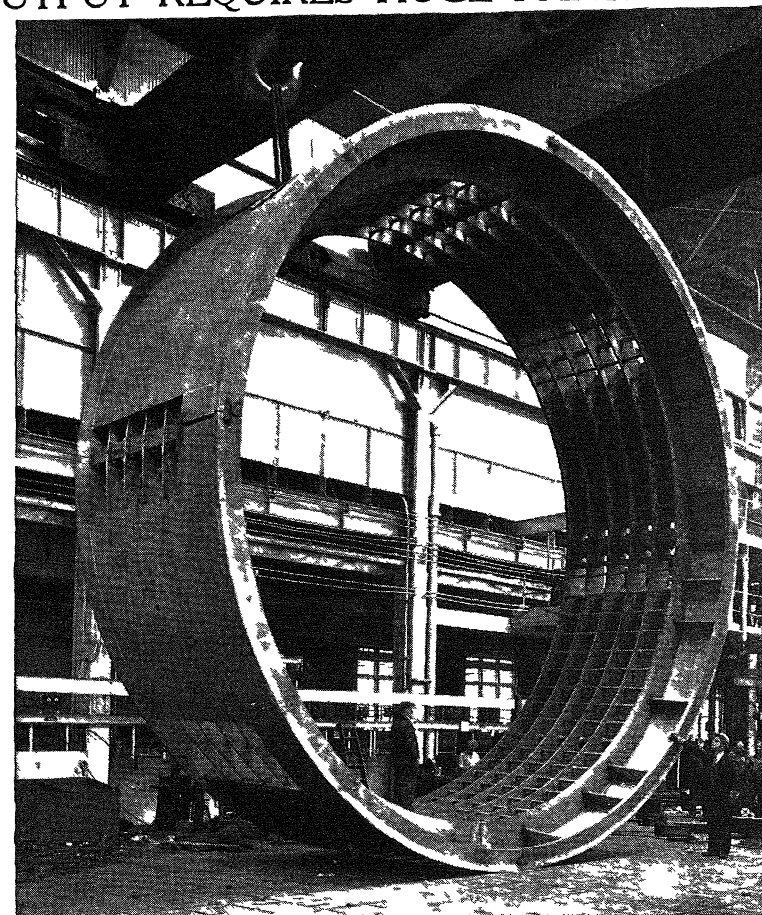
Built in less than five years, the dam rises 727 feet above bedrock. The powerhouse of the Hoover Dam has a capacity of more than 1,000,000 kilowatts. The inset shows the upstream face of the dam with Lake Mead slowly rising in the foreground.

HOOVER DAM'S ELECTRICAL OUTPUT REQUIRES HUGE PARTS



Photos courtesy General Electric Co

AN OIL CIRCUIT BREAKER FOR USE IN THE TRANSMISSION LINE BETWEEN HOOVER DAM AND LOS ANGELES



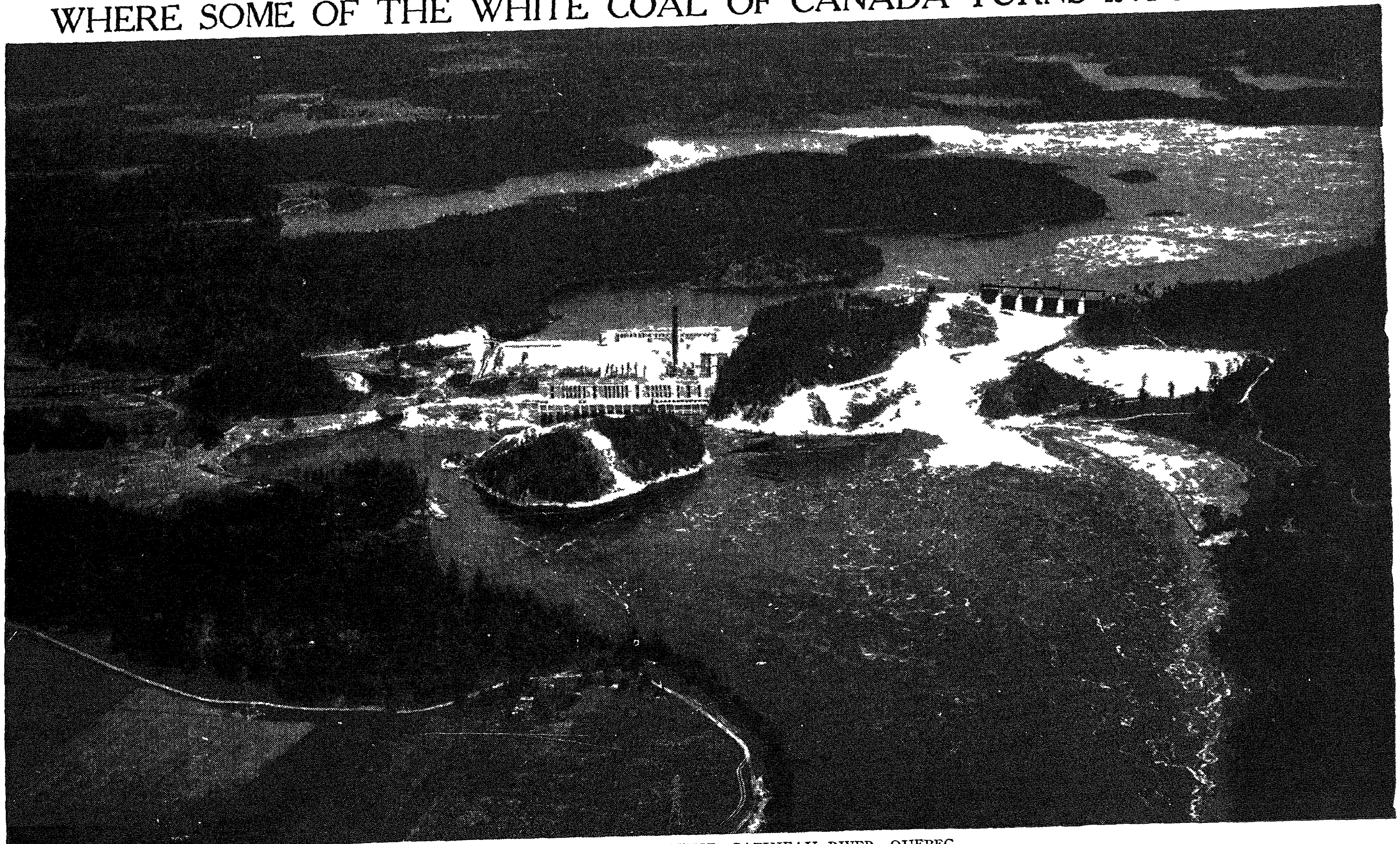
AN ARC-WELDED FRAME FOR THE STATIONARY ARMATURE OF A VERTICAL WATERWHEEL GENERATOR

SWIFT RIVERS FLOWING TO THE SEA DRIVE DYNAMOS FOR MAN

CHELSEA AND FARMER RAPIDS DEVELOPMENT, GATINEAU RIVER, QUEBEC

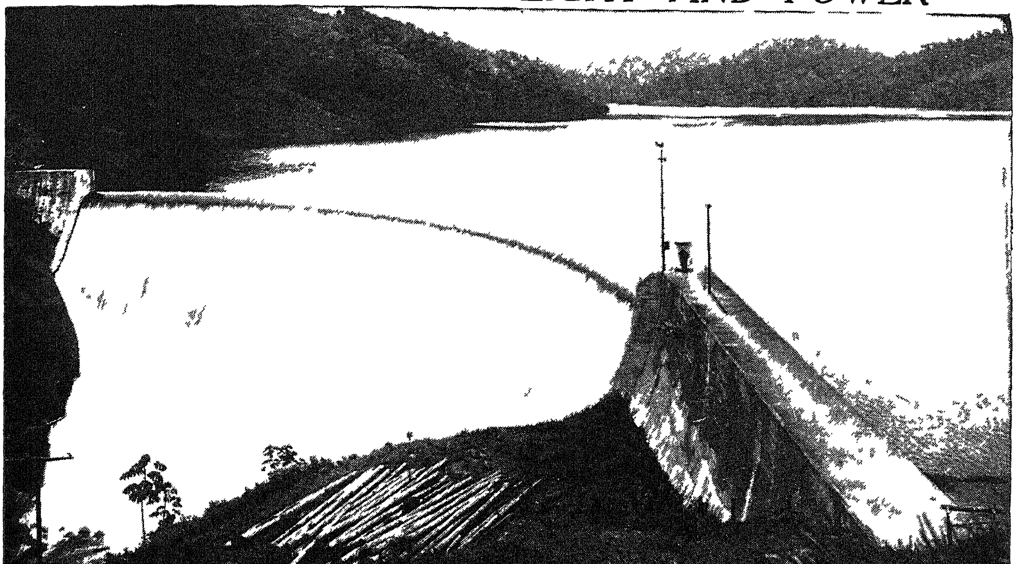
Chelsea development 136 000 h p, Farmer Rapids development 96,000 h p   Gatineau Power Company

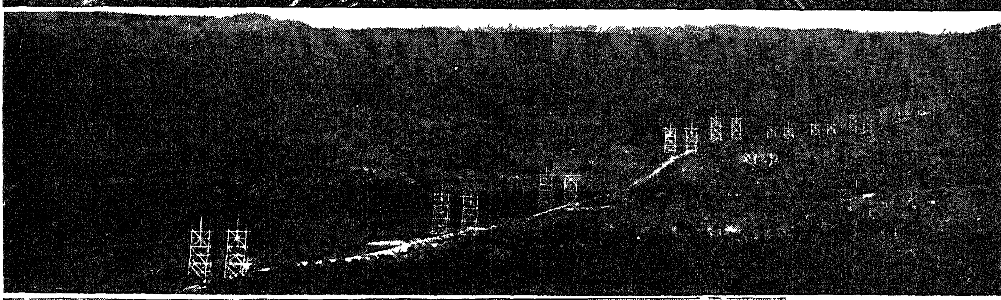
WHERE SOME OF THE WHITE COAL OF CANADA TURNS INTO POWER

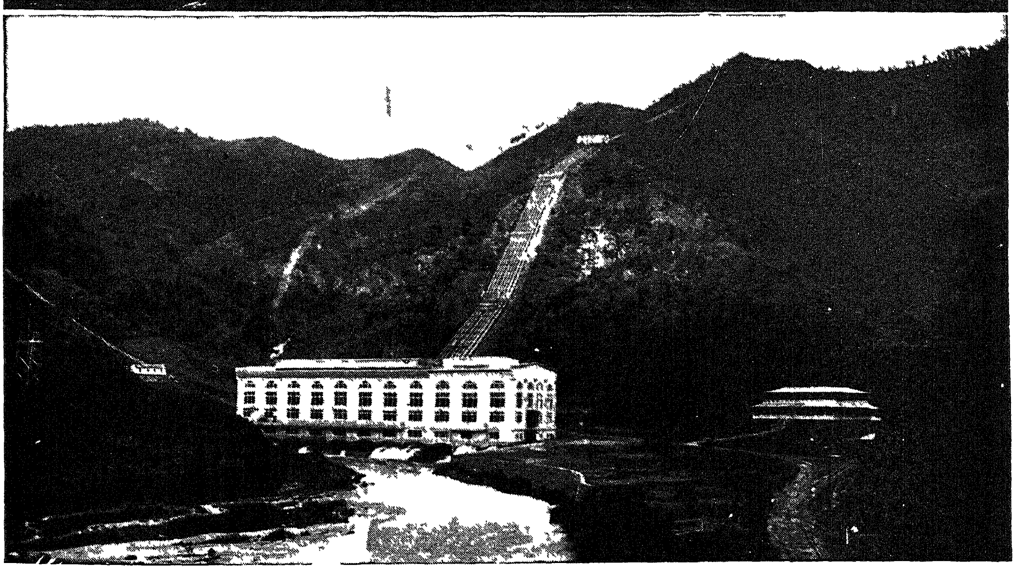


PAUGAN FALLS DEVELOPMENT, GATINEAU RIVER, QUEBEC
204,000 h p Gatineau Power Company

HOW RIO GETS ITS LIGHT AND POWER





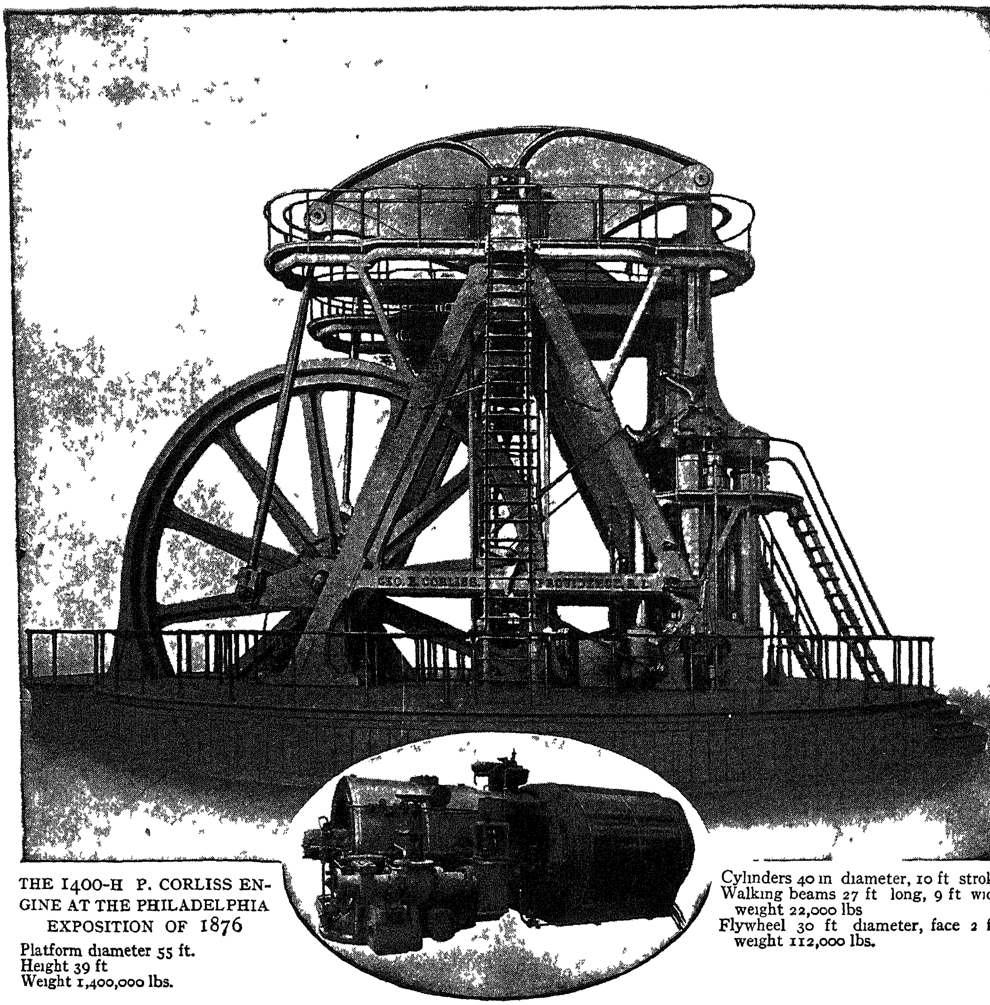


LIGHT AND POWER FOR THE CITY OF RIO DE JANEIRO

The dam in the Rio das Lages, 115 feet high and 705 long, built in a curve to better resist the pressure of the water in the 17-mile reservoir back of it, and set into the solid rock at each end and on the bottom.

The transmitting wires which carry the electricity 50 miles to the city.

The power-house where the transformation takes place.



THE 1400-H P. CORLISS ENGINE AT THE PHILADELPHIA EXPOSITION OF 1876

Platform diameter 55 ft.
Height 39 ft
Weight 1,400,000 lbs.

Cylinders 40 in diameter, 10 ft stroke
Walking beams 27 ft long, 9 ft wide, weight 22,000 lbs
Flywheel 30 ft diameter, face 2 ft., weight 112,000 lbs.

A MODERN 1400-H. P. CURTIS STEAM TURBINE

Length 17 ft. Steam pressure 150 lbs. per sq in.
Height 7 ft. Speed 3600 r p. m.
Weight 44,000 lbs.

A CONTRAST IN SIZE BUT OF EQUAL POWER

This illustration shows the difference in size between a reciprocating steam engine and a steam turbine of about the same power. In this particular plant the turbine is a low-pressure unit, using only the steam which has done its work in the reciprocating engine. The turbine will develop about 98 per cent of the power of the engine

At one time it seemed almost certain that all railways would ultimately be powered by electricity transmitted over long distances. Municipal street cars and subways had showed the advantages of electricity as a source of power for transportation systems. Long stretches of railroad track in the United States and Europe had been electrified. Travelers praised the convenience of trains powered by electricity, particularly the absence of soot and cinders.

Today the picture has changed considerably, particularly in the United States. Diesel-electric trains are being introduced in increasing numbers; in these, powerful Diesel engines drive electric generators and the generators provide power for the motors that drive the train. On some lines, too, modern streamlined steam locomotives have proved to be strikingly efficient. Yet, as far as we can see, there will always be a place for electrified railway trains.

DUST

Not deserving of so bad a
name as the housewife gives it

FRAMEWORK OF CLOUDS, CAUSE OF TWILIGHT

IT has often been demonstrated that this world of ours contains very few ugly, undesirable objects, and that even these, when truly understood, are of some use. No doubt we all agree with this idea in principle but deep down in our hearts we feel certain that there are some things which can have no possible value, especially any aggravating material such as dust Surely it is something to be swept up and gotten rid of; surely this bane of the housewife's existence is of no possible use to mankind and the less said about it the better. Yet, in reality, without dust the world would be far less beautiful than it is today and we would have great difficulty in living at all

Since few people realize the importance of dust, perhaps it would be well worth while to learn something of its origin and its usefulness. Is it a dirty, unlovely substance or is it a thing of beauty and a joy forever?

The amount of dust in the atmosphere

The dust in the atmosphere is usually made up of such small particles as to be invisible, only the giant members of this unseen horde being apparent. A ray of sunshine in a darkened room reveals the presence of a multitude of unsuspected motes or dust particles, which are constantly bombarding and jostling each other, with a tendency for the larger ones to settle down. Dust is everywhere, and its ability to penetrate tiny cracks and crevices is remarkable. After a two or three day experience with the annual spring dust-storm in any of the semi-arid Western States, one can well believe that dust is universal.

Even though we cannot see the usual dust particles, still it is possible to estimate the amount of dust in any given air space The density of the dust population varies widely from place to place, the air in a dusty city often containing more than 100,000 motes in a cubic centimeter, while the same amount of atmosphere above a mountain top may have only a few thousand or even less. Since a puff of cigarette smoke represents something like four billion dust particles, the daily smoke from even a single chimney will supply enough specks to stagger the imagination, and the total amount of dust in the atmosphere at any one time is beyond our conception.

The question naturally arises, how can these figures of the number of dust particles in a cubic centimeter of air be little more than a guess, since the usual dust particle is so small as to be invisible? Only by using an instrument called a "dust counter" can true estimates be made By this method, dust-laden air is admitted to a small chamber, 2 centimeters square, the bottom of which is covered with a glass plate ruled in square millimeters. The chamber is then cooled and the moisture in the air condenses on each dust particle and finally falls as drops on the ruled glass plate. These drops are counted and more water vapor is added to make sure that all of the dust has been brought down on the plate.

Owing to the universal presence and enormous amount of dust, it is evident that there must be widespread sources constantly supplying the atmosphere with more material

For convenience these sources may be divided into four groups star dust, ocean dust, volcanic dust, and earth dust.

Star dust: Almost everyone has seen meteors or shooting stars as they flash across the heavens. Each day billions of tiny meteoric bodies invade the earth's atmosphere and are destroyed by friction. Gas and very fine dust are all that remain in many cases.

The occasional large meteors that reach the earth have so far providentially buried themselves in very sparsely inhabited regions, and a terrible catastrophe would result if one should strike a densely populated area like New York or London. These visitors from another world follow irregular orbits, and it is impossible to foretell when a large one, like that which fell in Siberia in 1908, may survive the trip through our atmosphere and hit the earth. Fortunately, most meteors are destroyed by friction before they reach the earth.

Conservative estimates show that star dust to the amount of 100,000 tons is filtering onto the earth yearly and, since the earth's age is reckoned as hundreds of millions of years, the total accumulation of dust from this source is impossible of overestimation. In fact, one of the most widely-accepted theories of earth origin builds the earth itself by the accumulation of small particles from the wreckage of an ancestral sun.

Ocean dust: Strong winds whip vast quantities of spray from the ocean and, as a result, small particles of salt (sodium chloride) are added to the dust of the atmosphere. Salt dust is all-pervasive and traces of it are found in regions remote from the ocean. Naturally, toward the coast the amount of salt dust increases, and under favorable conditions it may form a considerable percentage of the material suspended in the air. The universal presence of salt dust may be readily shown by jarring a gas or oil flame and noticing the yellow flash. This jarring causes dust particles to fly up and their ignition gives the characteristic yellow color of incandescent sodium. Although not an important source of dust, the ocean has furnished notable quantities to the atmosphere since the waters were first foregathered.

Photo U S Weather Bureau

CLOUDS ARE CONDENSED ON DUST PARTICLES AND DEPEND ON DUST FOR THEIR EXISTENCE

Volcanic dust: Volcanic eruptions throw explosive material high in the air, up where the wind has great velocities and large transporting power. The coarser fragments settle down rather rapidly near the volcanic vent, and aid in building a volcanic cone; but the fine dust-like particles stay in the atmosphere for long periods of time and are transported to a great distance. For instance, the eruption of Krakatoa in 1883 added vast quantities of dust to the upper air, some of which made many trips around the earth before finally settling down. Records show that dust from this explosion formed a complete mantle around the earth within fifteen days, and some of it stayed in the air for three years. This gives a good idea of the extremely minute size of dust particles, and also indicates how they may be widely scattered.

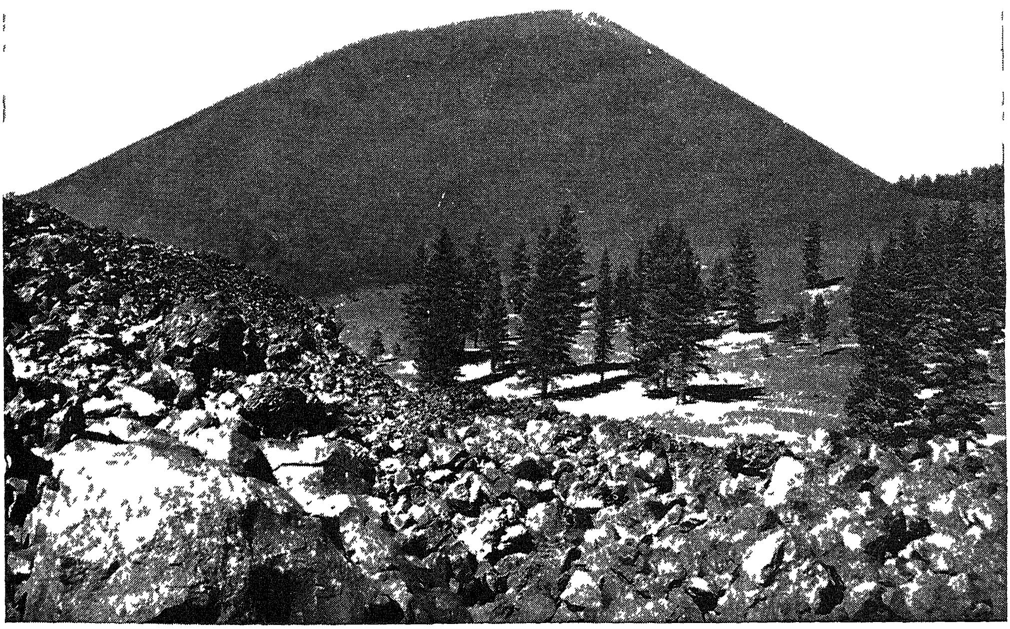


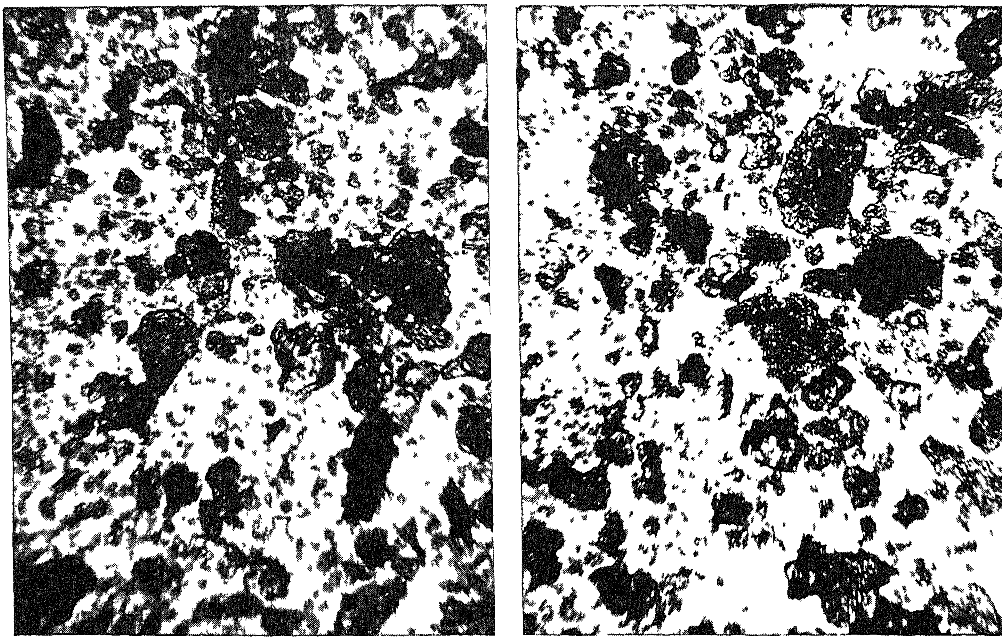
Photo Ewing Galloway

GREAT HEAP OF EXPLOSIVE MATERIAL

This lies along the side of Lassen Peak, the only live volcano in the United States. Dust from this explosion must have been noticeable for hundreds of miles.

Volcanic explosions furnish a most spectacular source of dust, and oftentimes the rate of accumulation is so rapid as to blot out many forms of life. Forty hours after one explosion, some fifty inches of dust had settled at a distance of ten miles, while even eight hundred miles away an accumulation of two inches quickly formed In Oklahoma and Kansas, volcanic dust deposits fifteen to twenty feet thick are now being dug to furnish the abrasive substance in cleaning powders and tooth pastes. Nature has here given a deposit of extreme fineness, and the individual little specks are very angular and resistant to abrasion. Beds of this thickness doubtless represent repeated accumulations over a long period of time, and, what is even more interesting, they are several hundred miles away from any past or present known volcano.

Earth dust: Wind may move material the size of peas by rolling, or it may temporarily lift sand grains and move them as dunes, but our main interest is in the smallest particles, which remain in suspension for long periods. When moving dust, the wind is usually at a disadvantage in that it is least able to suspend a load just where it must be picked up. For example, wind with a velocity of thirty miles an hour close to level ground may show an increased velocity of forty per cent on a hillock ten feet higher. Thus all the



VOLCANIC DUST FROM A 15-FOOT-THICK DEPOSIT IN KANSAS
The angularity and porosity of the grains are noteworthy Magnification 150 x

dust material must be lifted through this stratum of lower velocity before it can be handled to best advantage.

Dust picked up from the earth may be carried long distances before being dropped. One morning in 1918, the people in Wisconsin found everything covered with a thin veneer of reddish dust. The total fall was of the magnitude of some millions of tons, and at first it was thought to be the result of a distant volcanic explosion. Examination of the material under the microscope, however, showed its source to be very probably in the dry regions of Mexico.

Portions of Europe frequently receive dust from the Sahara, and the total thickness has been estimated to be five inches in the last three thousand years. The blood-rains and blood-snows of Italy are nothing but the result of a dusty, red Sahara atmosphere having its face washed.

Ships far at sea have frequently reported notable dust falls, and occasionally the air becomes so thick that the engines have to be slowed to half-speed. Even in high mountain areas the snow contains a considerable amount of dust, and the so-called "dust wells" are due to its presence. Here

Photo U. S. Weather Bureau

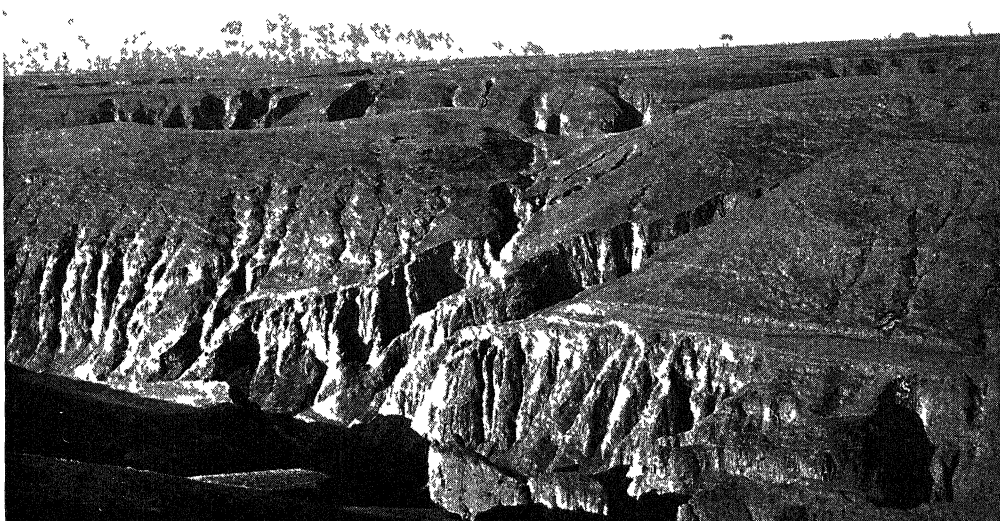
SANDSTORM PASSING OVER MIDLAND, TEXAS

Photo Ewing Galloway

TRAVELERS RETURNING FROM THE DESERT
Minor dust storms frequently occur in this part of Egypt

and there on the glacier's surface, little holes are formed where melting has been more rapid, due to selective absorption of the sun's heat by the dust.

Sometimes very thick dust deposits are made by repeated accumulation in favored places. Such loess deposits, as they are called, were formed extensively in the Mississippi Valley area, but the most striking in the world are those located in China. Here the loess has been built up to more than one thousand feet in thickness All of this material was derived from the Gobi desert, which today is a barren rocky waste, giving little indication of its former fertility. In fact, a large part of the fertile soil of China is wind-blown dust that has been transported long distances, the color of the Hwangho (yellow) River and the Yellow Sea furnishes additional proof that this soil is not firmly tied down but is easily transported.



THE THICKER LOESS DEPOSITS ARE CUT DEEPLY BY RAVINES AND GULLIES

PLANT ROOTS PENETRATE LOESS DEPOSITS TO A SURPRISING DEPTH

This illustration represents a vertical cliff fourteen feet in height, with a series of parallel columnar cracks extending the entire distance. It has recently been demonstrated by Dr. George B. Barbour that the penetration of plant roots is the true cause of these joints.

A characteristic of all true loess formations is their lack of bedding, or stratification planes. Such deposits have been accumulated very slowly, each thin layer as it was deposited being exposed long enough to the action of frost and rain so that all traces of bedding are destroyed. This lack of bedding, together with the enormous thickness of the loess, lead us to infer a long period of extremely constant wind action. Since loess is easily dug, and is quite warm and dry, many of the poorer Chinese families live in house-caves, and in certain areas these deposits are veritable labyrinths of passageways and tunnels.

Yes, dust picked up by the wind may travel long distances. Storms in the Grand Canyon district of the United States furnish material to all the world, and it has been aptly said that every square mile of the earth's surface contains dust from every other square mile.

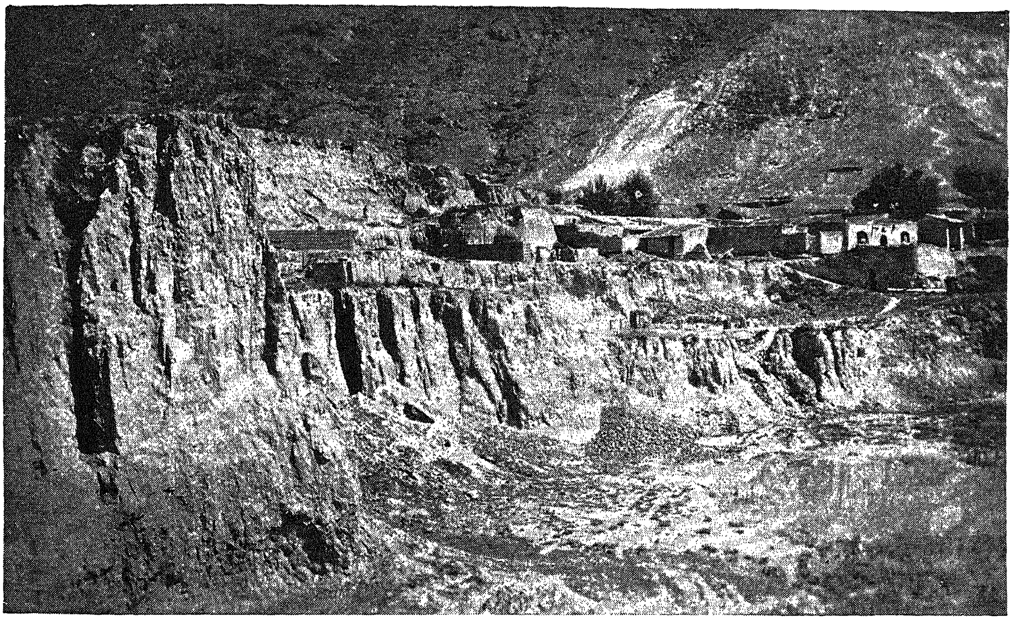
So far we have mentioned the sources of supply and the amount of dust, in order to appreciate that this universally distributed material is not an abomination, let us now briefly consider some of the benefits which result from its presence in the atmosphere.

The cause of colors in the sky

In a world free from dust, and from any atmosphere as well, the stars could be seen clearly both night and day. The sky itself would appear jet black. We sometimes forget that the bright blue of the sky is due merely to the scattering and repeated reflection of light. The heat rays, the reds and yellows, pass through the dust-laden atmosphere, but the blue rays, because of their shorter wave length, are retarded and dispersed.

Nearer the horizon the sorting of the light rays is more efficient, because there is a thicker layer of dust-laden atmosphere between the observer and the background of the sky, so that only the red, pink, and carmine rays get through. This is the explanation of coloring in the sunrise and sunset, and the greater the amount of dust in the air, the more gorgeously will the sky be tinted. Thus after the explosion of Krakatoa, the percentage of dust in the air

CHARACTERISTIC LOESS FORMATIONS



TYPICAL SCENE IN THE LOESS AREA OF CHINA

LOESS HOUSE IN SHANSI

Since loess is easily dug, and is quite dry, many of the poorer Chinese families live in these warm house-caves.

These illustrations, and those on pages 5173 (lower), 5174, and 5176, are kindly loaned by Dr. George B. Barbour.

was unusually large, and the records relate the most brilliant sunsets and sunrises since the beginning of historical time.

Who would wish to change the present coloring of the heavens? And yet, without dust, not only would the coloring be different but there would also be less diffusion of daylight, which would directly affect our eyesight, with probable dire results.

The cause of twilight

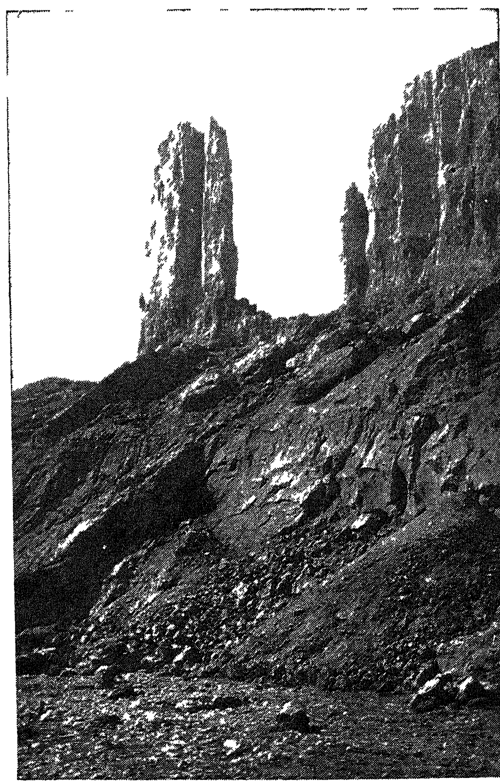
After the sun has gone below the horizon there is a period of twilight caused by reflection of light on dust particles and clouds. The more slowly the sun slips below the horizon, that is, the larger its angle, the longer twilight lasts. At the equator, twilight is a matter of a few minutes, while in the latitude of New York it continues for more than an hour. Without dust, the soft glow of twilight would be a myth, and presumably none of us are so unappreciative as to wish to lose this restful part of the day.

The framework of clouds

Acting as centers about which moisture collects is by far the most important service of dust. Many scientists think that condensation from the vapor to the liquid form of water would not be possible in the upper air unless dust acted as a nucleus So, without dust universally distributed through the atmosphere there would be few if any clouds; the earth would be watered by heavy dews instead of rain, and moisture would constantly condense on the ground and foliage.

It is difficult, if not impossible, to imagine what changes the rivers and streams would undergo if there were no rainfall. Geologic processes connected with transportation and deposition of sands and muds would be entirely different, and the sediments deposited in the ocean would have a new aspect. In the environment of a perpetually weeping earth, rock destruction would be speeded up; many of the present types of fauna and flora would be wiped out; decay would be widespread; and man's worst enemies, microbes and disease germs, would be masters of the world This presents a dreary picture, perhaps slightly overdrawn, perhaps greatly understated.

Many forms of life are today so delicately adjusted to their surroundings and so mutually dependent, that even the slightest change would produce far-reaching and startling disturbances. Take, as an illustration, Darwin's classic example of the effect of cats on the growth of red clover If field mice were not kept in check by cats, the nests of bumble-bees would be destroyed, the clover would not be fertilized, and therefore it would eventually die—all



TOWERING PILLARS OF DUST
Because of the unconsolidated character of loess deposits, erosion often cuts them into fantastic shapes

for the want of sufficient cats! Assuredly, any change in the character of the rainfall would be a calamity whose ever widening effect could hardly be exaggerated. Today many of our misfortunes, not only as individuals but also as nations, are closely related to droughts and floods. What would the world be like if for the past few thousand years there had never been any rainfall, but only continual dew? One hates to think of it.

The fact that dust acts as centers for the condensation of moisture, has been put to practical use by Professor Bancroft in a recent successful scheme for dispelling fog Following his suggestions, an aeroplane loaded with electrically-charged sand went through a fog-bank spraying the sand in all directions. Most of the moisture was immediately attracted to the charged sand grains and, condensing into large drops, fell as rain, thus dispersing the fog.

Of even more significance is the ability of dust to hold moisture in the upper atmosphere in the form of clouds. These water-vapor clouds subdue the heat and actinic properties of the sun's rays in the daytime, and retard the loss of heat from the earth at night. To put the statement simply and more forcefully, we may compare this action to a parasol by day and a blanket at night. Thus the underlying cause for the extreme changes between day and night temperatures in a desert region is lack of moisture clouds in the atmosphere.

The Soil Conservation Service

In recent years there has arisen a new term—the Dust Bowl. It refers to a part of the American Southwest, especially including portions of Colorado, Kansas, Oklahoma and Texas, where dust storms and wind erosion have led to the abandonment of farmlands like that shown in the illustration below.

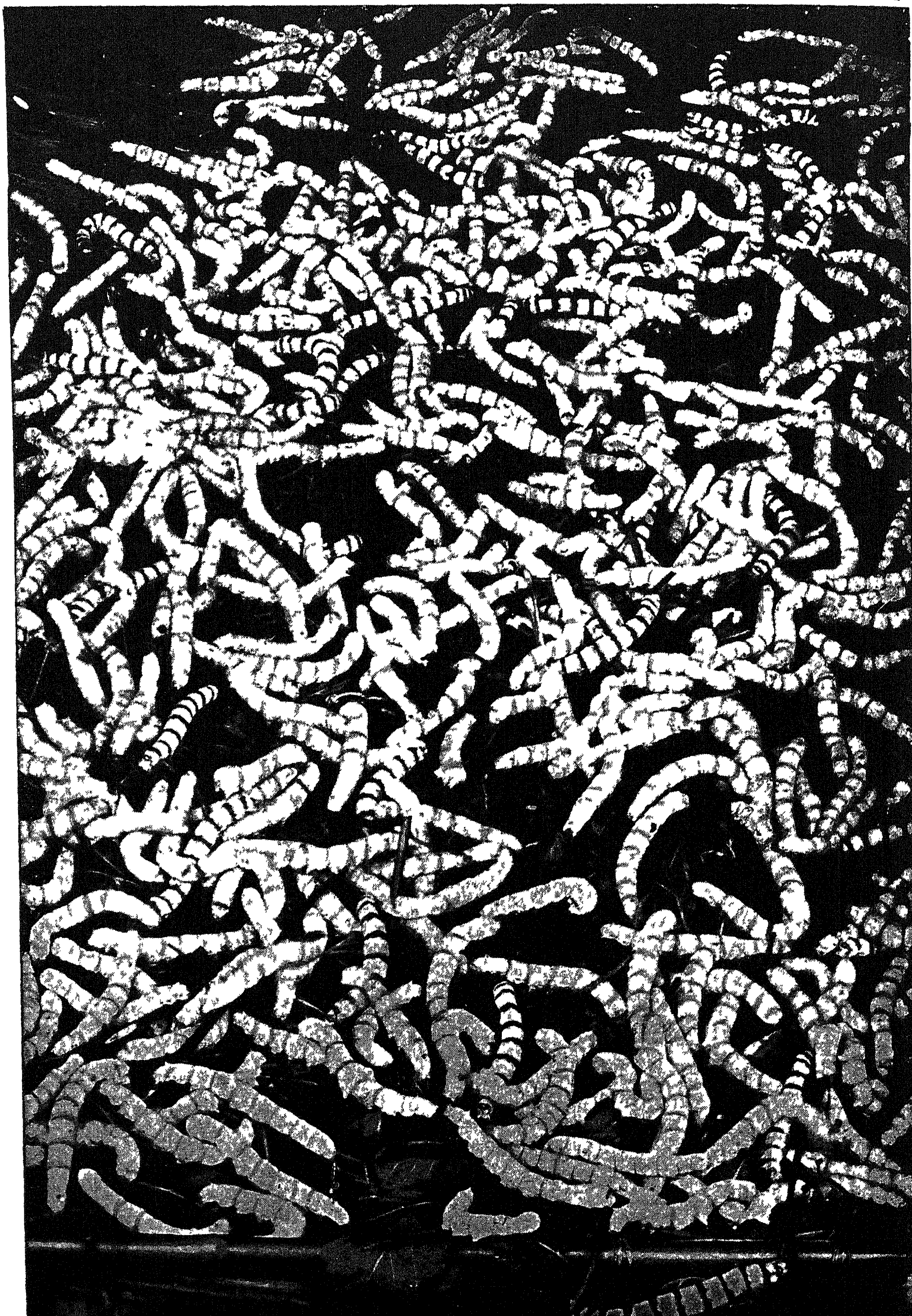
In 1929, the United States recognized the necessity of doing something about the washing, blowing and cutting away of farmlands. In that year a group of experiment stations was set up in various parts of the country to study the problem and to develop means of combating it. The start made in 1929 finally developed into a national program of soil conservation in 1933, when the Soil Erosion Service was established in the Department of the Interior. In April, 1935, the agency was transferred to the Department of Agriculture and named the Soil Conservation Service. With more than 200,000,000 acres of land already ruined or seriously damaged, the Service at the beginning of 1943 was extending active aid to over 800 farmer-organized districts, covering over 400,000,000 acres in forty-three states.

Photo by U S D A

DISASTROUS EFFECTS OF WIND IN THE AMERICAN "DUST BOWL"

An abandoned Oklahoma farmstead in ruin from the blasting winds which have shifted topsoil from the fields

THE TAMED WORM THAT CLOTHES THE RICH



A MULTITUDE OF SILKWORMS FEEDING UPON MULBERRY LEAVES AT SHIZUOKA, JAPAN

THE SILK INDUSTRIES

The Amazing Results of the Taming of a Moth Five Thousand Years Ago

THE STRIFE OF SILK-FARMER AND CHEMIST

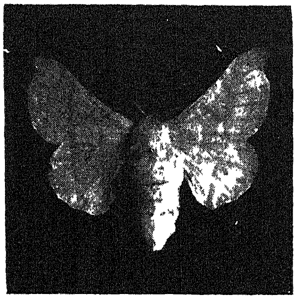
MAN has tamed many creatures to his uses, but the strangest and most curious of his essays in domestication is that of the silk-moth For about five thousand years an insignificant and feeble moth, about half an inch in size, has been kept working to make clothes for mankind It has been robbed of its natural strength, so that it can scarcely fly, and would certainly perish if it returned to its native forests on the Himalayas It is fed by hand, in light, airy, sheltered rooms, it is protected from disease by troops of human guardians armed with microscopes; and almost from the dawn of civilization mates have been chosen for it with more care than parents select husbands and wives for their children No race-horse, no prize-winning cow, has been bred so carefully as has the silk-moth for many thousands of years It has almost been refined out of existence by extreme domestication, for it has grown so feeble that the condition of its health has had serious effects upon the industrial life of great modern nations. And men of science are still busy trying to find some wild silkworm that will resist disease, and yet produce as fine and abundant a silk as the tamed variety does

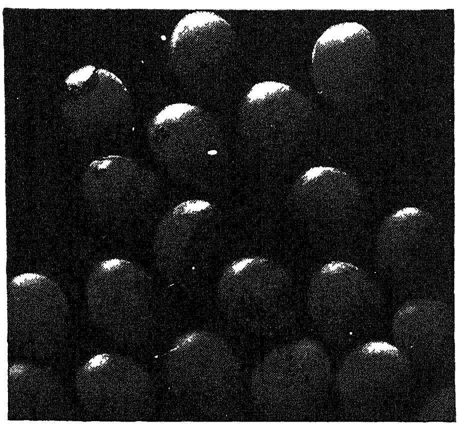
Every year the tiny moth is said to produce some 100,000,000 pounds of silk. This figure is probably an under-estimation of its extraordinary powers For the amount of silk that the Chinese consume themselves is probably very much greater than that which they export The silk-moths in Europe alone are reckoned to produce annually thread to the weight of some 11,000,000 pounds. We know that the total production of the silk-moths in China and Japan surpasses this amount many times Had it not been that towards the middle of the nineteenth century the moth had been so weakened by its strange artificial industrial life that it was almost swept clean out of existence by the attack of a microbe, India would now be a great silk-producing country, and so would France But at the present time Italy, China and Japan are unrivaled for the productiveness of their silk-farms India is still fighting against the silk-moth microbe, France has given up the struggle; while a number of scientists at Trent have been making a strenuous attempt to convert the poor, weak little moth into one of the principal workers in the villages of Tyrol

Recently a new silkworm has been discovered in Dalmatia It feeds on the leaves of oak-trees, and the fiber of its cocoon is said to be more abundant, finer and whiter than that of the common tamed silk-moth On the other hand, a wild variety of the domesticated creature has been found on the wooded heights of the Himalayas, so it is thought that these mountains were the original home of the wonderful little thread-maker that the Chinese captured on some mulberry-trees some time before 2640 B C, and removed forever from its native woods

The achievement of the patient and ingenious Chinese was really extraordinary Very likely they began by collecting the wild cocoons, as some of the jungle races of India still do They never search the trees, for it would be impossible continually to climb to the tree-tops in the hope of finding there a full-fed caterpillar that had completed its task of weaving a cocoon

The silk-hunters begin by searching the ground for droppings made by the caterpillars, and only when these are found do they climb the trees. If they are fortunate they may find some cocoons still unbroken; but very often the moth has escaped, leaving behind it only the ruins of the little silken house it made to shelter itself from foes while it was changing from an ugly caterpillar into a winged creature of the air. Perhaps it was after a disappointment of this sort that some Chinaman took to collecting the tiny eggs of the silk-moth, and keeping them until the caterpillars were hatched, and then feeding the caterpillars — or silkworms, as they are usually called — on the leaves of the white mulberry tree. But an infinite amount of care and labor was necessary before the wild moth was developed into the marvelous little domesticated spinner which the Empress Si-Ling-Shih first made famous by breeding it herself in the imperial palace. This was in the legendary ages of Chinese history, and legend attributes to the empress the invention of the loom for weaving silk into the beautifully patterned webs which thousands of years afterwards sold for their weight in gold in the Roman Empire.


THE SILK-MOTH

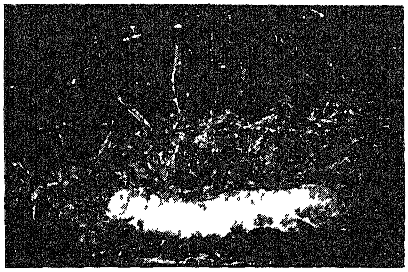

THE MOTH'S EGGS AS THEY APPEAR UNDER THE MICROSCOPE

By this time the silk-moth had become a great source of wealth to the Chinese nation, and there was a general conspiracy to keep the origin of silk a secret from all foreigners Inquisitive strangers were told that the beautiful material was obtained from the fleeces of sheep, which at certain seasons of the year were sprinkled with water in the sunshine to promote the growth of their exceptionally fine wool; and when this fine wool was combed out it was silk ready for weaving! But about sixteen hundred years ago the Japanese and the natives of India managed to discover the secret. The Japanese despatched a secret mission to China, and obtained some silkworms, and induced four Chinese girls to return to Japan and teach the people how to look after the wonderful moths The people of India conducted their campaign in a more romantic manner. The son of one of their kings wooed and married a Chinese princess, and the bride concealed some of the eggs of the silk-moth in her headdress, and on arriving in her husband's country taught his people the art of sericulture. Two and a half centuries afterwards two Persian monks of the Nestorian school of Christianity traveled from China to Constantinople with some eggs hidden in a hollow cane, which they presented to the Emperor Justinian From the precious contents of their bamboo tube, brought to Europe about the year 550 A.D., were produced all the generations of silkworms which stocked the Western World, and gave trade, prosperity and untold wealth to great communities for thirteen hundred years.


A SILKWORM SPINNING

Only a few years ago the Japanese tried to preserve the secret of a new kind of silk for which their country was becoming famous. When the silk-moth plague broke out in Europe and Asia, towards the middle of the nineteenth century, Japan was one of the few countries still unaffected It was from the sound eggs of her silk-moths that the silk-farms

of Italy and Switzerland and France were restocked. But the Japanese had also discovered a big wild moth in their own forests—six inches across the wings, and of a bright yellow color—which wove a large cocoon. The moth fed on oak-leaves, like the wild tusser silk-moth of the Indian jungles of central and southern India, but the thread of the Japanese moth was much finer and more lustrous; it was said, indeed, to be superior to that of the Chinese moth So no eggs were allowed to be sent out of the country. These, however, have now been obtained, but the art with which the Japanese breed and rear the moths still seems to be beyond the reach of the silk-farmers of India.

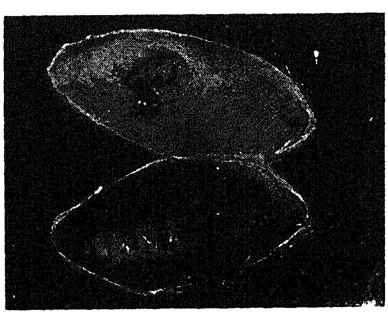


THE COCOON BEING SPUN

Until the moth plague broke out, the silk-farms of India promised to outrival those of China itself. For the domesticated Indian moth had developed a strange and valuable quality in its new tropical home. In temperate climes the moth breeds only once a year; in India the silk-farmer had four crops in twelve months. Now, however, he generally loses two entire crops every year, through the same plague that started in France in 1849, and spread throughout the world. It raged unchecked until 1866, when Pasteur discovered the microbe that produced it, and showed how sound eggs and healthy breeds could be obtained by the microscopic examination of the moths. Unfortunately, the small Hindu cultivators will not adopt the scientific method of protecting their stock. So their wonderfully prolific mulberry silk-moths are perishing; and most of the silk now produced in India is obtained from the tusser oak-feeding wild moth that spins an inferior kind of silk thread that is strongly impregnated with tannin.

THE COCOON BEFORE AND AFTER THE ROUGH SILK IS REMOVED

The eggs of the silk-moth somewhat resemble turnip-seeds. There are about a hundred to a grain's weight From an ounce of eggs and one ton of mulberry-leaves there are produced 140 pounds of cocoons, yielding about twelve pounds of raw silk. Very often the eggs are kept in cold storage to prevent them from hatching out before the mulberry-trees leaf in spring. This seems to have been done from time immemorial in China, by placing the eggs in jars partly immersed in a stream of cold running water; but in Europe refrigerating machinery is used. Again, when the mulberry-tree is putting forth its tender foliage, it is necessary in many countries to use incubators to hatch the eggs quickly and in a regular manner. Artificial incubation has always been a most important process in the rearing of silk-moths; and both Asiatic and European silk-farmers used to tie from one to two ounces of eggs in a small silk or cotton bag, and carry this about their person and next to their skin for three days. At night-time the silken bag was placed beneath a box under the warm pillow in the bed of the breeder. On the evening of the



A COCOON CUT OPEN, SHOWING THE CHRYSALIS WITHIN

third day the bag was emptied into a wooden tray, on which some shredded mulberry-leaves were scattered, and again placed beneath the warmed pillow, and in the morning the tiny little caterpillars began to break out of their shells. Then, on top of the hatching-box, a sheet of paper, full of large pin holes and lightly covered with shredded mulberry-leaves was placed. The tiny caterpillars crawled through the holes, and fixed upon the leaves, and when these were almost black with the creatures they were gently raised and placed upon feeding-trays. This method is still followed by Oriental nations, but in modern silk-farms much trouble and loss in broken eggs are saved by using artificial incubators. But it says much for the ingenuity of the Chinese race that they managed, four or five thousand years ago, perhaps, to devise both a simple cold-storage treatment and a kind of artificial incubation.

The domestication of the silk-moth involved problems of rearing far more difficult than the breeding of cattle and horses and sheep; and the manner in which the problems were surmounted is evidence of the patience and inventiveness of the Chinese mind. And when the Chinese begin to coöperate in a large way, as they already have in a small way, in the progress of modern science, this extraordinary patience and regard for little but important things will probably make them admirable in the most exquisite and laborious methods of scientific research.

PICKING MULBERRY-LEAVES IN A GROVE

It is also to the Chinese that we owe the cultivation of the white mulberry-tree, on which the silk industry largely depends. The ordinary mulberry-tree that is grown for fruit is not so valuable in silk-farming as the one that produces small and useless berries. The trees must be cultivated only for their leaves, and they must be fed with plenty of rich manure in order to develop their foliage as early as possible. Young trees, three or four years old, are best, and about five hundred of them will grow well on an acre of ground. Each tree should yield not less than twenty pounds of leaves in a season This is enough to feed a hundred silkworms, which will produce about a pound of cocoons; from these about two ounces of the best silk may be reeled, and the remainders of the silk-cases can be combed out like cotton and made into spun silk, which has about half the value of the natural silk thread.

At the beginning, the task of feeding the tiny caterpillars is easy, provided they have been hatched cut in considerable quantities at regular intervals. Each tray of silkworms, on the open shelves of the silk-farms, must be of the same age, so that they will all go through their processes of growth and their work of silk-spinning at the same time. When this has been arranged by means of cold storage and artificial incubation, the worms can be handled in a wholesale manner, without having to be touched and picked up singly by the farmer. Practically all that is needed is a warm and yet well-ventilated room with

open shelves on which the food can be placed without disturbing the little creatures. At first the worms will occupy a very small space on the shelf, but as thev grow larger they must be induced to scatter by spreading their food more widely. Young, tender leaves must at first be shredded for them, and served to them morning, noon and night. And as disease is produced if the leaves are damp, they must not be gathered with the dew upon them, or after a rain. So it is best to keep in hand a couple of days' supply of food, to tide over the exigencies of bad weather in the mulberry plantation.

Four times in the course of their brief life the caterpillars fast for some days. In these periods of apparent rest they slough off their skins, and in about a minute they appear in a new and larger coat. In this way they grow at last to the size of about three inches. The time they take in passing through their four moltings depends upon the warmth of the season and the climate. In Japan each period is about five days long, excepting the first, which is about seven, and the last, which is about ten. It is after the last molting that the labor of the silk-farmer grows really hard. The caterpillars must be fed late at night and early in the morning and several times during the day, and great attention must be given to the quality as well as the abundance of their food. For they are now amassing the material which they intend to spin into silk. Air and light must be freely admitted into the room, and the

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THE MULBERRY-TREE THAT WAS INTRODUCED INTO EUROPE FROM THE FAR EAST TO FURNISH FOOD FOR THE SILKWORMS

great litter that the worms now make must frequently be cleared away, and all their surroundings kept neat and clean

Having arrived at their utmost growth of two and a half to three inches in length, the caterpillars will cease to eat, and crawl about the shelf, searching with outstretched heads for a nook in which to spin. The spinning-places are provided by the farmer in a number of ways. Often a screen of interlaced twigs is erected around the shelves, the space between the twigs being so arranged that the little spinner need not waste much of its silk in hanging its cocoon among the branches Little tubes of hollow bamboo or paper are also furnished by some silk-farmers, to save the spinner the trouble of making a web among the twigs. In China large mats are placed by the shelves, the whole surface of the mats being covered with curled strips of material that form spiral rounds, about an inch apart. Between these rounds the worms spin, without wasting any of their floss in making a kind of airy scaffolding to support their silken house.

PLACING EGG PACKAGES IN AN INCUBATOR

On finding a fit place, the silkworm begins its work by spinning some thin and irregular threads to uphold the future structure. Upon these it forms on the first day a kind of oval of a loose texture, called the "floss silk"; and within this oval, in the next three days, it fashions the firm and valuable ball of silk. It always remains on the inside of the ball, and there, resting on its hind part, it fastens and directs the thread with its mouth and forelegs The thread is not fixed round and round on the inside of the ball, but is spun backwards and forwards in a wavy figure; and this is why a ball, in reeling off its silk, will not often turn round once while ten or twelve yards of thread are being drawn out.

Twenty-four hours after beginning to spin, the little worker is hidden from view; and in from three to five days it finishes its cocoon, in shape and size somewhat like a pigeon's egg By this time the industrious caterpillar has lost half its weight and shrunk to half its size Housed in an egg-shaped lodge, it molts for the fifth time and changes into a chrysalis, shaped somewhat like a kidney bean, but pointed at one end and having a brown, smooth skin composed in rings, with its cast coat lying inside the ball with it Left to itself, the chrysalis molts for the sixth time, and softens with a liquor from its mouth one end of the cocoon, and then loosens and pushes aside the wet silk, and emerges as a small, white, feeble moth. If it is a female, it has scarcely the strength to flutter its wings.

It is fairly easy to select about an equal number of males and females for breeding purposes, as their cocoons are differently shaped. The creatures live but for a few hours, and are so feeble that they have to be mated by the silk-farmer. Each female moth lays from three to four hundred eggs, and then dies shortly after its partner. The eggs are collected and examined, and then put in cold storage for the spring.

At the Bacological Institute of Trent three hundred women are employed night and day in catching the moths in cells of gauze or waxed paper as they emerge from the cocoons The cells are hung from the ceiling, and in them the moths lay their eggs and die About three million cells are used, and from them are obtained twenty-five thousand ounces of eggs. Some women open the cells, some remove the dead moth and crush it for examination by forty women armed with microscopes. If no sign of disease is found, the eggs are kept in the Institute through the winter, and in April they are taken out of the cold storage room and distributed to customers in the villages of Tyrol

MAKING BEDS FOR THE YOUNG CATERPILLARS ON WHICH THEY GROW AND ARE FED

This is the way in which all the silkworm seed of a country should be obtained A central breeding-station, with its scientific appliances, is able to keep the national stock of silk-moths free from microbe attack. Moreover, by conducting its operations on a large scale, it can sell the seed at a very low price. The Trent Institute, for instance, sells its seed at one-third of the ordinary cost. It buys selected cocoons from the breeders, brings a few of them rapidly to maturity in incubators, and thus tests the quality; and if this is satisfactory the bulk of the cocoons is placed in boxes, and the chrysalises are there allowed to develop in a normal manner. By this modern method of

breeding, the Tyrolese are quickly winning their way to a position of considerable importance in the European silk market, using French science in building up an industry that now seems lost in France.

A well-organized body of progressive silk-farmers could by the same method rapidly raise India to her old position as a silk-producer. For they would have one of the cheapest supplies of labor in the world, and a climate in which four crops of silk could be obtained every year. The furnishing of a silk-farm is extremely simple and inexpensive, particularly in a hot climate where little or no artificial heat is ever needed. Some open sheds, in which are long, light frames for holding lightly woven mats of reed on which the caterpillars live, and some brushwood or Chinese mats for the spinning of the cocoons are practically all that is required, in addition to the mulberry plantations surrounding the sheds.

Nowadays, few silk-farmers reel their cocoons. These are usually collected and dealt with in factories. At least, this is done in Europe at the present day, and it is becoming somewhat of a general practice in China and Japan. Home-reeled silk, taken from the live cocoon, is more lustrous than factory-reeled thread, and this is why both the raw silk and the woven fabrics of China are more brilliant than the products of Europe. On the other hand, the system of factory reeling results in a more even and stronger thread. And as strength of thread is a vital necessity in weaving on power-looms, the brilliant luster preserved by the old-fashioned method is now generally sacrificed.

THE SILKWORM'S WORK COMPLETED — COCOONS FROM WHICH RAW SILK IS OBTAINED

IN A JAPANESE SILK FACTORY

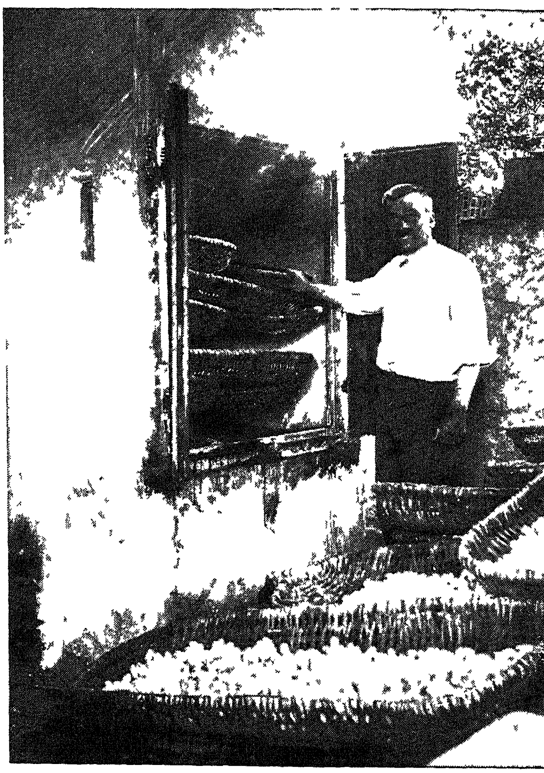
Silkworms are fed on mulberry leaves and grow rapidly. At last they are ready to spin their cocoons. The workers above are preparing trays of fibers, on which the worms will weave their houses of silk.

Both photos, Philip Gendreau

After the cocoons have been spun, the chrysalises within them are killed by being subjected to steam or hot air. The cocoons are then carefully sorted by skilled workers, as shown above.

By whatever method the cocoon is reeled, the task is quite easy. The silk ball is thrown into a tank of warm water to soften the silk-gum and set free the fiber. The loose outer case of floss silk is then removed, and the end of the thread forming the true cocoon is readily found The thread is several hundreds of yards long, and it is this extraordinary length of unbroken fiber which distinguishes silk from cotton, linen, wool and other weaving materials There is no need to card it and twist it; it needs only to be unreeled Yet it is so fine that thirteen hundred yards weigh only the seventeenth part of an ounce This extreme tenuity, however, is of no practical use So the reeler usually takes six cocoons from the tank, and passes their threads over a rod, and through the eyelet holes of the machine, through which they run in a compound thread on to a revolving wheel

When reeled into skeins the material consists of raw silk. It is composed of two substances secreted by the silkworm — fibroin and serecin Fibroin is a horny kind of substance that forms the core of the thread. It cannot be dissolved in water, even at boiling heat The serecin can be so dissolved, for it is a kind of gum deposited on the surface of the thread. As produced by the silkworm, silk consists of two fine strands of fibroin, slightly twisted together and coated with the gum. The fiber is about the three-thousandth part of an inch in thickness, and of remarkable strength. A twisted thread of it, finer than the finest human hair, will stretch half a foot to the yard, and support a weight of about a pound. No other fabric material is so strong. Pure silk is both more beautiful and more durable than any vegetable fiber; and if it were not now so terribly adulterated it would often prove more economical in use than all fabrics of cheaper stuff



THE STOVE FOR SUFFOCATING THE CHRYSALIDS

The first step in the manufacture of silk is known as "throwing". The skeins are soaked for some hours in warm, soapy water, and then dried and stretched on a light skeleton reel called a "swift" Having found the end of the thread, the woman winder passes it through a guide wire and lightly attaches it to a revolving bobbin As the bobbin revolves it draws the thread from the wheel, with so gentle a motion that if the threads stick through any reason the machinery stops Thus the breaking of the thread is avoided, and hundreds of yards of continuous fiber are neatly wound on each bobbin The thread is afterwards rewound over a double knife that cleans the silk of all unevennesses and hairy filaments.

The next process is sometimes called spinning, but the proper term is "throwing". For silk does not need to be spun, except when it consists of the little broken fibers obtained from the outer covering of the cocoon. It already consists of a long, continuous thread, and as soon as it is cleaned it can be woven into pongees. But to make stronger fabrics the single silk is twisted into a little compound thread on a throwing-frame. The action of the frame

depends on two sets of bobbins that revolve at different speeds, and, by the way in which their revolutions are adjusted to each other, more or less twist is given to the thread thrown. The two chief varieties of thrown silk are organzine and tram To the organzine a great deal of twist is given, to make it hard and strong.

It is used for warps, which are the long, lengthways threads of a web that are tightly stretched in the loom before weaving begins. They bear the strain and the friction of weaving, and thus need to have great strength and evenness. Tram is less twisted than organzine, and therefore more soft and flossy. It is used for the weft or filling, the crosswise thread that knits the warp together into a web of fabric. There is little strain on the weft, but it must be soft and bulky, so that its successive threads may lie close together and fill up the interstices of the silk.

The eighteenth century, which was marked by so many epoch-making inventions for the improvement of textiles, including Kay's shuttle (1733), Strutt's ribbed stocking frame (1758), Hargreave's spinning jenny (1770), Arkwright's roller spinning (1771) and Crompton's mule (1776), changed spinning from a hand to a machine operation, and was the real beginning of the factory system, ushering in the revolution that followed the application of power to industry Inasmuch as silk requires much more delicate handling than either cotton or wool, most of these inventions were in use in the cotton mills 20 years before they were successfully applied to silk. In 1801 Joseph Marie Jacquard of Lyons exhibited at the French Exposition his machine for weaving patterns, in which cards replaced the system of cords and complicated tie-up of the draw loom. Jacquard suffered from the usual hostility meted out to inventors, was burned in effigy and his machine smashed by the crowd, but today most figured designs are woven on a Jacquard loom.

A JAPANESE WOMAN REELING THE SILK OFF A COCOON

In making cheap silk, the thread is woven as soon as it is thrown — that is to say, the silk is not first boiled and dyed. Good silk goods, however, are woven from yarn-dyed thread. The skeins of silk are first boiled, in order to extract the gum and the color. Before being boiled, silk is harsh and wiry, resembling somewhat fine horsehair. It also differs in color, according to the place of its origin. Italian silk is yellow; Chinese and Japanese wild silk, light fawn in tint; while the best Chinese silk is nearly white. But the boiling extracts the color as well as the gum, and leaves the thread of fibroin soft, white and brilliant. The weight of the material is also considerably lessened, sixteen ounces being reduced to twelve after being boiled for two hours in soapy water and then rinsed thoroughly to get rid of the gum and soap. Copper tanks, known as "barcs", are used in dyeing. The skeins of silk are hung on sticks that rest on the edges of the barc, leaving about three-quarters of the skein submerged in the bath of liquid dye. By turning the skein on the stick at regular intervals the dyer gets all the material equally colored.

The liquid in the barc is formed of the water in which the silk has been boiled, and with it is mixed the dye-stuff, which is either a natural product or an alizarine synthetic chemical, the ordinary aniline dyes being unworthy of being applied to good silk. Before being placed in the dye, the skeins are immersed in a solution of certain chemical salts, which prepares them for the action of the dyes. This process is called "mordanting"; and sometimes, when two skeins, that have been differently mordanted, are afterwards placed in the same dye they acquire entirely different colors. While the silk lies in the dye, steam is turned on, and the liquid is gradually brought to boiling-point. The dyer tests the coloring process by taking a skein off one of the sticks and drying a few of its threads. If the tint is right, the silk is rinsed very thoroughly. Then each skein is hung on a wall-peg and twisted by means of a stick, with all the force that the dyer can use. This is called "scrouping": and though it may seem a severe process for so delicate a thread as silk, yet the fiber is so strong that the harsh wringing only enhances its glossy luster. After the dyer has squeezed the silk nearly dry, the skeins are finished in a drying-room, and they are then rewound on bobbins ready for the weaver.

Unfortunately, both yarn and piece-silk are greatly adulterated at the present time. The boiling removes much of the natural gum, and lessens the weight by about one-quarter, and, to make up for this, unscrupulous dyers and manufacturers resort to "loading". Silk has a great affinity for water, and it can absorb one-third of its own weight without feeling wet to the touch. But the dyers soon found that it would absorb other things besides water, and especially solutions of salts of tin and iron. Indeed, silk will take up so much of these metals with the dye that twelve ounces of boiled fiber can be increased in weight to eighty ounces, and still look like very bright silk. Most people like silk bright and shiny. They are so accustomed to the adulterated material that they cannot recognize a piece of pure silk when they see it. As a matter of fact, pure silk has a subdued, pearly luster, whether it is merely boiled off and freed from the gum, or carefully dyed with pure color.

Very brilliant silk owes its brilliancy to the great amount of metal or vegetable matter with which it has been adulterated. Many silks in the market are now heavily loaded, and it is almost impossible to purchase pure silk goods that will stand the test of time and wear. The breaking-strength of a given unit of dry China raw silk is, say, 53. But some French silk, dyed blue-black and very heavily loaded, has a breaking-strength, for the same given unit, of $2\frac{1}{5}$. This, we will admit, is the worst case known to us; and an ordinary loaded silk may often be purchased with a breaking-strength of 10 or 12. But this is only about one-fifth of the original strength of the best natural silk.

Now, a silk can be made from wood-pulp with a strength of $21\frac{1}{2}$ when dry, and a little under $5\frac{1}{2}$ when wet. Thus, at its weakest, it is superior to a very heavily loaded natural silk in a wet condition.

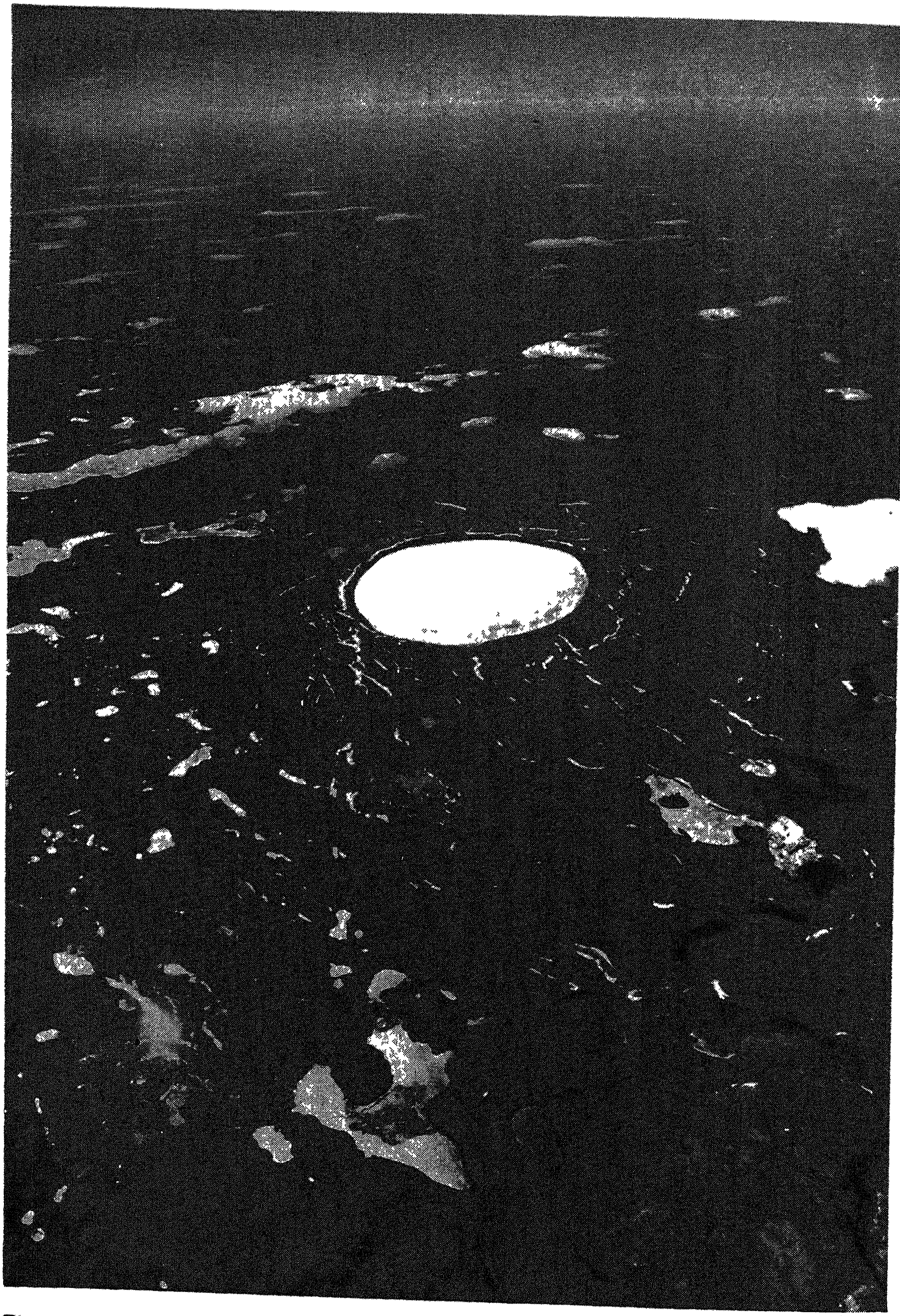
This is the reason of the rapid development of the new process of making artificial silk, called rayon since 1924. Tests show that rayon always becomes quite weak when it is wet. The same thing happens to a less extent with boiled natural silk. It has a breaking-strength of, say, 25½ when dry, and only of about 16½ when wet. At present the best kind of rayon is practically as strong in its dry state as the best boiled-off natural silk, but when it is wet it is about 2½ times weaker than wet natural silk. This disadvantage has not interfered with the large and still rapidly increasing use of rayon; and we are inclined to think that, if the loading of natural silk continues, the marvelous product of the silk-moth will be generally excelled by the creation of the chemist.

At present there are four processes of manufacturing rayon from wood-pulp or any other cheap source of cellulose. In the first process, covered by French and German patents, nitric acid is used. To prevent the nitrated thread from burning or exploding, like gun-cotton, the nitrate is afterwards removed, forming a product which is now an ordinary staple textile. In another German invention the wood-pulp is treated with a mixture of copper and ammonia. A third method is the viscose process. The latest is the cellulose acetate method. In the viscose process for making rayon, the wood-pulp is first treated with a mixture of caustic soda and water, and when drained looks like bread crumbs. It is then put in a churn, and on it is poured a quantity of bisulphide. It turns yellow in the churn, and grows slightly warm, and water is then stirred into it and it is passed through a very fine filter. There are several ways of forming the liquid into a thread. In one it is sent through a number of fine glass tubes, and the separate threads are united in passing through a glass loop. In a second method it is sent through a nozzle of platinum, perforated with fourteen to eighteen holes. Each hole contributes a thread, and all these threads are drawn forward through a tank of liquid chemicals, which purifies the viscose. In the form of a compound thread, the strands ascend a glass roller and fall through a funnel into a spinning-box. By its motion the box draws the thread forward, and twists it, and lays it down in the shape of a hollow cocoon. In this form the rayon is taken at intervals from the spinning-box, and rewound into skeins, and further manipulated for the purification of the cellulose. Rayon, when it is thus prepared, is much stronger than that obtained by the other processes, yet it is still inferior to unadulterated natural silk in its resistance to rain and moisture.

Although several attempts have been made to produce raw silk in the United States, none of them has been really successful, not because mulberry-trees and silkworms cannot be raised in this country, but because silk cannot be grown by the highly paid labor of the United States in competition with Oriental and Italian drudgery. But the manufacture of silk goods, as with all other textiles, has been so revolutionized in recent years by the application of inventions and power, that the silk manufacturers of the United States, essentially the home of the machine, not only include some of the greatest concerns, but produce much of the best silk in the world. In Colonial days such silk as was made here was reeled by hand, thrown or twisted and doubled by hand, and woven on a crude foot-power loom at home by the women of the family.

The first silk-mill in the United States seems to have been started by Rodney and Horatio Hanks, at Mansfield, Connecticut, in 1810. The mill was but twelve feet square, and was intended to make sewing silk and twist on a machine of their own devising, run by water-power. In 1815, William H. Hortsmann built a mill in Philadelphia for trimmings and ribbons in which he attained partial success with machines for plaiting, braiding and fringe cutting. A Jacquard loom was imported by him in 1824. The first really permanently successful silk manufacturers in the United States were the Cheney Brothers of South Manchester, Connecticut. Their original mill was started in 1838.

A HUGE PIT DUG BY NATURE



R.C.A F.

The Chubb Crater, the world's largest, forms the basin of the lake shown in the center of the photo.

THE PIT OF UNGAVA

How the World's Largest Crater Was Discovered

IN the course of the second World War the Royal Canadian Air Force made a number of aerial photographs in Ungava, a barren region in the northern part of the Province of Quebec. Not long after the end of the war, Fred W. Chubb, a veteran Canadian prospector, was examining one of these photographs when a striking detail attracted his attention. To his surprise the picture showed a round little lake in an area where the lakes were generally grotesquely irregular in shape.

"Perhaps," thought Chubb, "the basin of this lake is really a volcanic crater, like the basin of Crater Lake in Oregon." That set his thoughts turning in another direction. He recalled the theory — by no means universally accepted — that diamonds are formed by volcanic action. He wondered whether the volcanic eruption that, as he thought, produced this crater might not be the source of nearly a hundred fine diamonds that had been found scattered far and wide in a fan-shaped area far to the south. If this were so, he might be able to find an even greater number of diamonds in the immediate vicinity of the crater.

Chubb decided to take the photograph to a well-known mineralogist, Dr. V. Ben Meen, the director of the Royal Ontario Museum of Mineralogy and a member of the University of Toronto teaching staff. Dr. Meen enlarged the picture on a screen and examined it carefully. In the enlargement the picture showed quite clearly a high, circular rim that rose above the surrounding area. Dr. Meen thought that the rim must have been formed between three and five thousand years ago. He reasoned that it must certainly have come into being after the disappearance of the immense glacier that had once covered the entire area; otherwise it would have been relentlessly crushed by the glacier, with its great ice masses moving slowly over the land

There were two possible explanations for the origin of the crater, in Dr. Meen's opinion. It had been caused either by a volcanic eruption or by the crash of a huge meteor or swarm of meteors. (See the article, A Cosmic Bombardment, in Volume 9.) Dr. Meen thought that the crater could hardly be of volcanic origin, since neither explorers nor Eskimo legends had ever reported traces of volcanic ash or of far-flung lava in that particular region.

He came to the conclusion that the newly discovered crater was caused by the impact of a meteor or a swarm of meteors. There are a number of craters that were undoubtedly formed by a meteor or meteors. The largest of these is Meteor Crater, in Arizona's Canyon Diablo. It is 4,000 feet in diameter and 570 feet deep, with a rim that rises from 130 feet to 160 feet above the surrounding plain. Thousands of meteorites, weighing up to 20 tons, have been picked up in the vicinity of the crater.

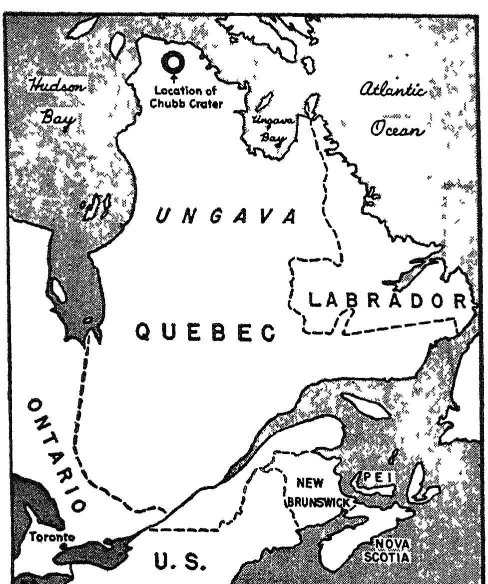
There are also a number of craters of meteoric origin at Henbury, Australia. The largest is 660 feet in diameter; the smallest, 30 feet. There is a large crater in Texas, too — the Odessa Crater, with a diameter of 530 feet. There is a group of comparatively small craters in an uninhabited area of central Siberia, located at longitude 101°57′ E. and latitude 60°55′ N. They were caused by a group of meteors that flashed across Siberia on June 30, 1908, scaring those who beheld the spectacle almost out of their wits. There is ample evidence, then, that meteors can dig vast pits in the earth's surface.

Both Chubb and Dr. Meen were anxious to examine the newly discovered crater at close range. Chubb felt that he might find diamonds in the vicinity, even if the crater had been formed by a meteor or by a group of meteors, since diamonds have been

found in meteoritic masses. Dr. Meen was eager to inspect a crater that promised to rival the largest known up to that time.

The two men, backed by a Toronto newspaper and various individuals, organized an expedition to visit the site of the crater. On July 16, 1950, they set out with a small party on an amphibious plane from Toronto. It took them four days to fly the 1,600 miles from Toronto to the crater; but at last they caught sight of the little round lake. It was covered with ice; snow lay upon the ridges that surrounded it and that rose from 300 to 500 feet above the surface of the lake. The plane entered the "arena" formed by the ridges and flew low over the jagged ice of the lake. Then the big amphibian climbed up and out and settled on a near-by body of water. The members of the expedition carried their luggage ashore by canoe and set up a camp.

For five days they crawled about the crater and also explored the surrounding district. Dr. Meen took pictures, made sketches and searched for evidence of lava or meteorites. On the last night he called the members of the expedition together and summed up his findings. At some time or other, perhaps three thousand years ago, he



Map showing the location of the Chubb Crater, in the desolate area known as Ungava.

said, a gigantic meteor roared into the earth's atmosphere, and the friction of the air began to slow its fifty-mile-a-second speed. This friction caused the meteor to become so hot that it glowed with a blinding light. As it finally crashed into the solid granite of Ungava, it exploded with cataclysmic force and blew out an immense crater in the earth. Huge ridges of granite bedrock spread in concentric circles from the center of the crater — just as water ripples spread when a stone is tossed into a pond. At the same time millions of chunks of granite were flung aloft by the explosion that had created the big pit.

The present appearance of the crater site

To support his theory Dr. Meen pointed out that the huge granite boulders that were tossed upward by the force of the explosion are found scattered over the plain for many miles around. He remarked, too, that in the crater itself there are huge crevasses, or splits, in the solid granite. There are three series in all: horizontal splits on the inner and outer slopes; lateral, or sidewise, splits on the crest; and splits that, like rings, girdle the inverted cone that is formed by the crater. All of these signs, according to the noted mineralogist, confirmed his theory that the crater had been formed by an explosive force that had driven downward.

In the summer of 1951, Dr. Meen returned to the site of the crater, and this time he found definite proof that it was indeed of meteoric origin. He identified tons of meteoric fragments scattered around the big pit. Using mine detectors, he found evidence that a huge mass of iron lies buried under the eastern rim of the crater.

The huge dimensions of the Chubb Crater

The big pit has been named the Chubb Crater in honor of the prospector who first made out its outlines in a photograph and who was among the first to explore it. The Chubb Crater measures more than 2 miles from one side to the other and it is 1,350 feet deep. It is by far the largest meteoric crater upon the face of the globe.

THE ORIGIN OF KINGSHIP

Superstition as a Social Force

THE ordinary Englishman of today would laugh heartily at the suggestion that his king is descended from a god. The English monarch would certainly lay no claim to any of the qualities possessed by the heathen deity Woden, whose name we preserve in our word "Wednesday" or "Woden's Day." He does not even touch for the King's Evil, as Queen Anne touched the boy who was later to become the great Dr. Samuel Johnson. No doubt he would say, as King William of Orange is reported to have said when a man flung himself at his feet praying to be healed by the royal touch: "God give you better health and more sense!" Yet ancient records enable us to trace back the English kings to the pagan days when they prided themselves mightily on the fact that they were human gods, with Woden as their not too remote ancestor.

The sun-goddess and the Japanese Mikado

The Mikado of Japan, chastened by the nation's reverses in World War II, would be as little likely as the English monarch to press his claim to be a god in human guise. Yet he, too, is supposed to be the lineal descendant of a deity. Japanese legend informs us that the sun-goddess graciously came down to earth, made a nation of certain savage Japanese tribes and ruled over them. Legend goes on to report that she gave birth to a child who later became the first mikado of Japan. In the days that followed, every mikado was worshiped by his people as the incarnation of the sun-goddess. Up to the middle of the nineteenth century there was one month in the year in which nobody frequented any of the Japanese temples. It was useless, people said, because all the shrines were deserted by the gods. They were spending a month at the mikado's court, humbly paying reverence to him!

It is well known that the emperors of China were considered to be the sons of heaven. One of the principal reasons, perhaps, why the Manchu dynasty was overthrown and replaced by a republic was the fact that the strange "new" line of northern barbaric chiefs had no superstitious hold on the mind of the people. The history of their conquest of the throne was much too recent for them to revive effectively the ancient tradition of the sovereign's divinity.

The widespread belief in the divinity of kings

This tradition has at one time or another been practically universal in monarchical governments. The early Babylonian kings, from Sargon to the kings of the fourth dynasty, claimed to be gods in their lifetime. The pharaohs of ancient Egypt were worshiped as sons of the sun-god, and so were the emperors of Peru. The earliest kings of Rome were earthly Jupiters—sons of the god of the sky and the thunder and the oak tree. Less is known about the primitive kings of Greece, but what little we do know seems to indicate that they were supposed to be persons with supernatural attributes. In fact, all the Aryan races from India to Ireland were originally governed by rulers who were supposed to possess divine powers, by means of which they could make the earth fertile and alter in various ways the course of nature. The deification of the Roman emperors, which caused such scandal among the early Christians and led to their persecution, was not an extraordinary circumstance. On the contrary, it was only a revival of one of the commonest customs of the primitive monarchy in many lands.

It is difficult for us to understand it, because our ideas of divinity differ so greatly from the ideas that the pagan races of the world still retain on that subject.

They cannot rise to our conception of a Divine Power of a purely spiritual nature. Some savage tribes have, it is true, a notion of a Divine All-Father, but they regard Him as a kindly human ancestor who has been exalted to the spirit world. Their idea of the universe is so narrow and childish that they cannot get beyond the idea of a ghostly magician of a benevolent nature. In short, their gods are ghostly magicians, their magicians are living gods

It must be remembered that every savage is, in his own opinion, endowed with tremendous powers. All that the man of science now dreams of accomplishing, the savage has for hundreds of thousands of years calmly assumed that he achieved by means of magic. The wild wonders that happen in our genuine fairy-tales are traditions of the childhood of our race, when man lived in a world of mystery which he thought he could mold to his heart's desire by babyish rites of magic. Such was the mental atmosphere in the days the wizard welded tribes into kingdoms.

The secondary place filled by fighting-men in superstitious tribes

Before Professor J. G. Frazer completely revolutionized our ideas of the origin of the higher forms of government, it was generally assumed that brute force had prevailed in the making of the earliest nations. Undoubtedly the warrior has been a constructive force in human affairs; and in a previous part of this work we showed how much the sword has done in consolidating mankind, introducing new elements of culture among backward races, and enforcing the coöperation necessary for progress to civilization. But in the earliest societies the fighting-man is often less potent than the magician. Not by force of arms but by the power of superstition is government maintained in the rudest of existing social groups representing primitive man.

The blackfellows of Australia, for instance, are not ruled by their best fighting-men, but by very old wizards. The social organization is loose, and it has often been mistaken for a primitive democracy, with neither chiefs nor kings. But as a matter of fact it is a harsh and tyrannical oligarchy of old men. It is a government by elders; and the headmen undertake the task of performing magic ceremonies for the multiplication of various animals and plants on which the clans live. In short, most of the headmen are magicians who are assumed to provide the people with food. Others have to cause rainfall and render similar services.

How men careless of bodily harm succumb to ghostly fears

They are public wizards. Their most important function consists in taking care of the sacred storehouse, usually a cleft in the rocks or a hole in the ground, in which are kept the holy stones and sticks of the tribe. With these stones and sticks the souls of all the people, living or dead, are bound up. The wizard calls the tribesmen together for initiation ceremonies and public discussions. In fact, he is a chief in all but name, and if he aspires to great influence he must be a skilful conjurer. For some tribes in southeastern Australia have reduced the test of all candidates to headmanship to a simple matter. The greatest headman, according to their way of thinking, is found in the man who can produce the largest number and variety of things from his inside. A "magician" like Houdini would easily defeat a Cæsar or Napoleon in a contest for the chieftaincy of any of the lower savage tribes.

This will at once be clearly understood if considered from the point of view of the savage. He does not fear any bodily hurt. Many savage races are continually engaged in warfare. Every expansion of population leads to quarrels about territory, which end at last in the ordeal of battle. As a rule it is the young fighting-men who are most eager to resort to the use of force; and if there were no means of keeping them in check, they would rebel against the authority of the old men.

It is here that the influence of the tribal wizards tells. Taking a cunning advantage of the wildly superstitious nature of the savage, they rule him by ghostly terrors and magic customs until he cannot, literally speaking, even call his soul his own.

They can raise up ghosts to haunt him, cast awful spells upon him, and even make him waste away like a wax image before a fire. And all this can be done secretly, so that the punishment falls in a sudden and mysterious manner without any warning. What is the power of a man who can throw a spear or use an ax a little quicker than his fellows, compared to the ghostly abilities of a magician? When the matter is looked at in this light, the marvel is not that kingship largely arose out of wizardry, but that any warrior chief of a later date ever succeeded in subordinating the witch-doctors of the tribe.

The difficulties of usurpation in lands where superstition reinforces kingship

In New Guinea the level of culture is higher than it is among the blackfellows of Australia, but many of the races are still unorganized into chieftainships. Now and then, however, some renowned wizard manages to get into the position of a temporary king. Wars, marriages, deaths, raids and fishing and hunting expeditions are all under the dominion of the magician. For nothing would prosper unless he had been consulted about it, and given offerings to perform the rites that bring success. He is the master of life and death and so he is feared and obeyed in everything he demands in a way that no man relying on mere force could command.

One man of the Taoripi tribe of British New Guinea has been made a chief because he can rule the sea, calming it or rousing it to fury at his pleasure. Another owes his power to his skill in making the rain fall and the sun shine, and compelling the trees to bear fruit. The present chief of Wedau is also famous as a rain-maker and a wind-controller. In this stage of society the road to power is open to all the talents. Everybody practises magic and believes in it, but some men have more self-confidence than others. Perhaps they are more intelligent and less impressionable than the majority of their fellows; anyway, they grow bold enough to lay claim to the possession of supernatural powers of an unusual nature, and succeed in convincing the people they possess them.

Where chieftainship depends on direct inheritance of magical powers

Such seems to be the method by which some sort of central authority is obtained by an able and cunning man among the lowest races now known to us. When ancestor-worship develops into something like religion, the wizard chief is often able to hand on his authority to one of his sons or male relatives. In some of the South Sea Islands, for example, the power of the chiefs rests on the belief in their spiritual and magical genius, and this genius is derived from the spirits of ghosts with whom they have intercourse. In any case of difficulty they are able to bring down on their enemies the influence of the spirits. If a chief imposes even an unjust fine, his people pay it, because they are afraid that if they anger him he will bring a plague.

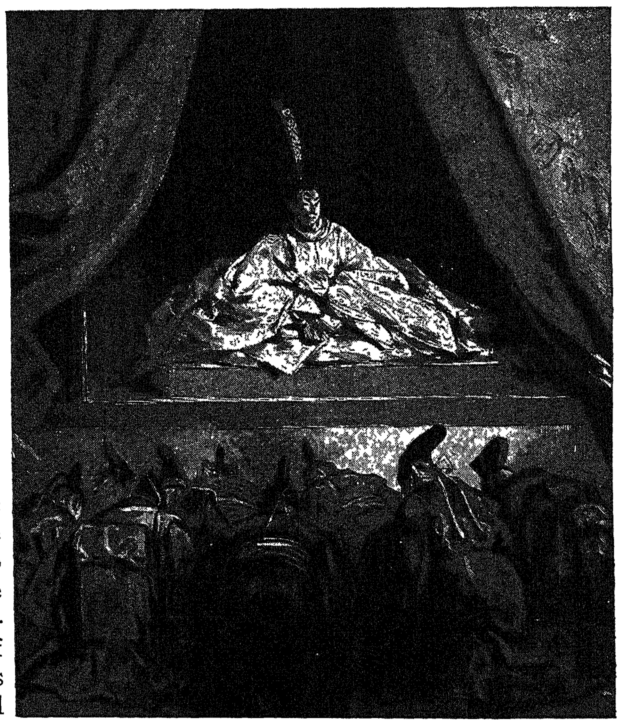
In one of the New Hebrides there is a nobility which, like most primitive aristocracies, is founded upon wealth. But the wealth is used in a very curious way. Those persons who have been able to afford it have sacrificed a thousand little pigs to the souls of their ancestors. Nobody dares in any way to resist a man who has carried out this sacrifice. For in him are supposed to dwell all the souls of the ancient chiefs and all the spirits who preside over the fluctuating fortunes of the tribe.

The spiritualistic medium of the modern era who asserts that he is on terms of familiar intercourse with Julius Cæsar and Mahomet and the rest of the mighty dead possesses many of the advantages of a New Hebrides nobleman, but our incredulity prevents him from making the best of his very aristocratic connections. Had he lived two thousand years ago he might, if circumstances had favored him, have become the king of his tribe. Had he then possessed some military talent in addition to his spiritualistic ability, he could have gone forth to conquest and founded a nation.

As a political instrument, the apparatus of a magician is more useful than the ax of a warrior. A soldier chief of primitive or savage race cannot always make sure that his descendants will inherit his powers.

They may be only young men, and not so strong of body and full of courage as he was; and their claim to the leadership may be disputed by some older man with more experience and fame in war. In the absence of any superstitious reverence for the offspring of a self-made leader, a nation would probably be destroyed by tribal and personal jealousies and ambitions long before its internal industrial development so consolidated it that it could survive recurring periods of anarchy. Where, however, something of the prestige of magical power still attaches to the kingly office, kingship can descend from father to son.

In northern New Hebrides, for instance, a son does not directly inherit the chieftainship; but as he knows his father's magical incantations and possesses his sorcery stones and other magic instruments, he is usually able to succeed to the office. Moreover, the son of a wizard chief is often regarded by savage people as an incarnation of the father. As soon as the father dies, his spirit enters the body of the son. What becomes of the soul of the son in this case is a matter of which we have no knowledge. The superstition, however, is very useful in maintaining the continuity of a central power of government and preventing usurpation and disorder.



THE DIVINITY OF KINGS — THE OBEISANCE OF THE NOBLES TO THE MIKADO OF JAPAN

The Japanese regard their mikados as the successive incarnations of the sun-goddess. So when a soldier usurped the kingly power during the wild feudal wars, the sacred person of the monarch had to be respected.

The victorious usurpers maintained their power over the popular mind only by imprisoning the mikado, and pretending that he was so holy that he could not be seen, and thus could only act through them. They professed to be humble servants of the royal god — in somewhat the same way as the usurpers of power in Tibet shielded their "eternal and heavenly father" from the public gaze — and they carried on the government ostensibly as his human servitors

The way was thus left open, through all the disorders and civil wars of Japan, for the mikado to assume full and direct authority when the chiefs of the clans awoke to the fact that their country was endangered by their jealousies and jarring ambitions.

Usurpation is always difficult in a primitive monarchy. It means, looking at the affair from a primitive point of view, no rain, no crops, cattle sickness, and a plague among the people. All the spirits of the dead chiefs conspire to punish the nation, and no ordinary magician can prevail to avert these disasters against their combined efforts.

When, in ancient Ireland, Carbery Kinncat usurped the throne, the chroniclers relate that only one grain grew on every wheat stalk, and no cow gave any milk. In Scotland, the stone on which a king sat to be crowned showed if he were not of the royal race. It is now used in Westminster Abbey at the coronation of the ruler of the British Empire, but it has apparently lost its power of speech.

People who regard the royal regalia as a wonder-working talisman

The regalia of royalty may very likely be derived from the instruments of magic that the wizard chiefs of old bequeathed to their descendants. We have already seen that the symbols of a great sorcerer are still very effective in enabling his son to assume authority over a savage tribe. In the Indian Archipelago the regalia are regarded as the fount of regal dignity. In southern Celebes the royal authority is even supposed to be embodied in some mysterious fashion in the symbols of kingship. The princes owe all the power they exercise, and all the respect they enjoy, to their possession of these precious objects. In short, as Professor J. G. Frazer remarks, the regalia reign, and the rulers are merely their representatives. So whoever happens to possess the regalia is regarded by the people as their lawful king.

If a deposed monarch contrives to keep the sacred insignia, his former subjects remain loyal to him in their hearts. His successor is merely a usurper, and obeyed only in so far as he can exact obedience by force. So the first aim of rebels in any insurrection is to seize the regalia; and if they are successful the authority of the sovereign is gone. Temples are built for the regalia to dwell in, just as if they were living creatures, and furniture, weapons and even land are assigned to them. In times of disaster they are brought forth as instruments of magic for the purpose of staying the evil. Sometimes the regalia consists, like the instruments of the savage magician, of stones and pieces of wood and curious dried fruit. When a missionary asked to see some of these objects, the native guardian replied that if he were to open the bark-cloth in which they were wrapped there would be an earthquake!

Thus in the Malay region the regalia are still merely wonder-working talismans which the modern king seems to have inherited from the ancient magician. So we may conjecture that in other parts of the world the emblems of royalty may have had a similar origin. In ancient Egypt, for instance, the two royal crowns, one white and one red, were supposed to be endowed with magical qualities. They were divinities, being, like Pharaoh, embodiments of the sun-god. Sometimes the guardianship of the magician instruments is a source of great inconvenience to the wizard chief.

A few years ago the headman of Etatin, on the Cross River in southern Nigeria, was an old man whom the people had compelled to take office in order that he should look after the fetishes or "ju-jus," and work magic for the benefit of the community. In accordance with an ancient custom, which is binding on the head chief, he was never allowed to leave the inclosure in which his house stood. He gave the following account of himself to a foreign visitor.

"I have been shut up ten years, but, being an old man, I don't miss my freedom. I am the oldest man of the town, and they keep me here to look after the 'ju-jus,' and to conduct the rites celebrated when women are about to give birth to children, and other ceremonies of the same kind. By the observance and performance of these ceremonies I bring game to the hunter, cause the yam crop to be good, bring fish to the fisherman, and make rain to fall. So they bring me meat, yams, fish, and other offerings. If I were to go outside this compound, I should fall down dead on returning to my hut."

Control of the elements one of chief duties of a primitive king

The kings of Mexico took an oath when they were crowned that they would make the sun shine, and the clouds give rain, and the rivers flow, and the earth bring forth abundantly. Such were, indeed, the principal duties of the monarchs of old. The Chinese emperor always held himself personally responsible for very severe droughts and many self-condemnatory edicts in this matter used to appear in the Peking Gazette. The rulers of Korea and Tonquin were also blamed for bad harvests, typhoons and epidemics. When things were very bad, the Tonquin king changed his name. If that did not remedy matters, he transferred the kingship to his brother or son, or some near kinsman.

Kings of olden times even sacrificed for failing to ward off famine

The office of a king certainly had some amazing disadvantages in primitive days. A magician who could not work magic at the proper time was often in danger of losing his life. The fact that his people were too profoundly superstitious to dream of questioning his powers only increased his peril in adverse circumstances. A succession of bad harvests never showed that the royal art of rain-making was an imposture. It only convinced the people either that their king was spiteful and bent on doing harm to his subjects, or that the spirits were punishing the people because they did not get a better king.

The Edonians of Greece put their king, Lycurgus, to death during a very bad harvest. The Burgundians usually deposed their rulers whenever the crops failed; and in a famine the Swedes sacrificed King Comalde to their gods. The Scythians put their king in bonds when food was scarce, and did not release him until he relented and worked the magic that made the people happy. More chiefs and kings throughout the world have fallen because rain did not come at the proper time than have been deposed because of any sound political reason.

There are, indeed, cases where a change from monarchical government to republicanism has been brought about entirely by superstition. On Savage Island formerly reigned a line of wizard kings who were supposed to make the food grow. But a succession of bad seasons set in, with the result that the kings were killed one after another, till at last no one would undertake the office of kingship. So the monarchy came to an end.

The dangerous honor of a kingship depending on health

It is still not uncommon to find among savage and barbaric races another strange peril attaching to the kingly office. The magician first climbs to chieftainship, and then acquires divine qualities. To the mind of a savage, the difference between a powerful sorcerer and a god is not clear. His gods are often merely hidden magicians. So he is ready to regard his kings as human gods, and to obey them with extraordinary humility. A god, however, must not be subject to human maladies. At the present day many petty kings of Africa are bound in honor to commit suicide as soon as they feel themselves to be ill. So much depends upon the royal magicians being in a fit state to exercise their supernatural powers that their health becomes a matter of supreme national importance. Strange ordeals have been employed to test the continued strength of the king. There have been many monarchies in which at stated periods the ruler had to engage in a deadly combat with any man who cared to fight for the crown. The earliest kings of the Roman people, for instance, had to enter once a year a sacred grove, and fight against any rival. And in India, as late as 1743, the king of Calicut had either to cut his throat in public at the end of a reign of twelve years, or to stand on a ridge, at some distance from the temple, and fight continually for twenty-eight days against the best of his youngest swordsmen.

How the ordeals on which kingship depended have been evaded

Generally speaking, the primitive kings of the world were able to surmount the difficulties which they created for themselves by their pretension to magical and divine powers. Men of masterful character merely used at last the magician's wand to clear the way to the throne. Having won it, they maintained themselves by the power of the sword, and reduced the annual fight or other periodical ordeal to the empty form it often assumed in historic times. The kings of Rome, for example, avoided the sacred grove, and appointed some criminal to be the annual king of the wood, and the custom became a yearly conflict between malefactors and outcasts. And the king of Calicut, when the twelfth year of his reign arrived, took his accustomed station on the bridge but surrounded himself with forty thousand fighting-men. No swordsman ever cut his way through the long barrier of spears.

How rulers sometimes evaded responsibility for control of the seasons

The responsibility for the control of the seasons and the supply of food was evaded, in many cases, by delegating the functions of looking after the weather and the health and prosperity of the people to a class of subordinate magicians, like those that Moses encountered at the court of Pharaoh. Moreover, in most of the earliest civilizations the practices of totemism and fetishism developed into a system of idolatry. The animals which the primitive magician of the tribe once had to make to flourish were raised to the rank of gods, and left to look after themselves. If they did not attend to the wants of the people in spite of the prayers and sacrifices offered up to them in seasons of drought or plague, their images were taken from the temple and beaten and dishonored.

The rise of royal despots beneficial compared with savage wizardry

All this saved the persons of the kings, and enabled them to kick away the ladder by which they had climbed to the throne. Giving up the use of the black art, without, however, relinquishing their "divine rights", they became priestly despots, and, as such, they emerge into the light of history. The general result of the evolution of the savage wizard into a royal despot was to place the supreme power in the hands of men of the keenest intelligence and the most unscrupulous character.

The change from the primitive oligarchy of old men — all of them magicians — to a monarchy in which the rule of a single ruler prevailed was, on the whole, beneficial. As Professor J. G. Frazer remarks, no human being is so hide-bound by custom and tradition as the apparently democratic savage. He is a slave, not, indeed, to a visible master, but to the past — to the spirits of his ancestors, who guide his steps from birth to death, and govern him with a rod of iron. In no other state of society is progress so slow and difficult. Scarcely any scope is afforded for men of superior talent to change old customs for the betterment of the community.

First great strides toward civilization made under despotic governments

From this low and stagnant condition of affairs, the cunning magician uplifted his duller-minded fellow-men by playing on their superstitious fears. The rise of one man to supreme power enabled him to carry through in a single lifetime changes which many generations might not previously have sufficed to effect. It is not an accident that all the first great strides towards civilization were made under despotic and theocratic governments, where the supreme ruler received the servile allegiance of his subjects in the double character of a king and a god. At this early epoch the despot often was a liberator. Under the most grinding of early tyrannies there was more liberty of mind and soul than under the apparent freedom of savage life, where the lot of the individual from cradle to grave was, and is, cast in the iron mold of hereditary custom. Here is the conclusion formed on the matter by Professor Frazer:

"So far as the public profession of magic has been one of the roads by which the ablest men have passed to supreme power, it has contributed to emancipate mankind from the thraldom of tradition, and to elevate them to a larger, freer life, with a broader outlook on the world. This is no small service rendered to humanity. And when we remember further that in another direction magic has paved the way for science, we are forced to admit that, if the black art has done much evil, it has also been the source of much good; that if it is the child of error, it has yet been the mother of freedom and truth."

Of course, other factors, beside superstition and wizardry, concurred in the evolution of the earliest forms of government. There was, for instance, the terrible ordeal of battle, which acted as a selective agency between neighboring but quarrelsome groups. If superstition weakened a people instead of giving it more cohesion, that people became broken up in the next period of fierce warfare. Thus the power of wizardry was somewhat checked and directed by interaction with other social forces.

A BEAR AND A DOG AMONG THE STARS

An artist's idea of the constellation Ursa Major, the Great Bear. From a drawing by D. O. Stephens.

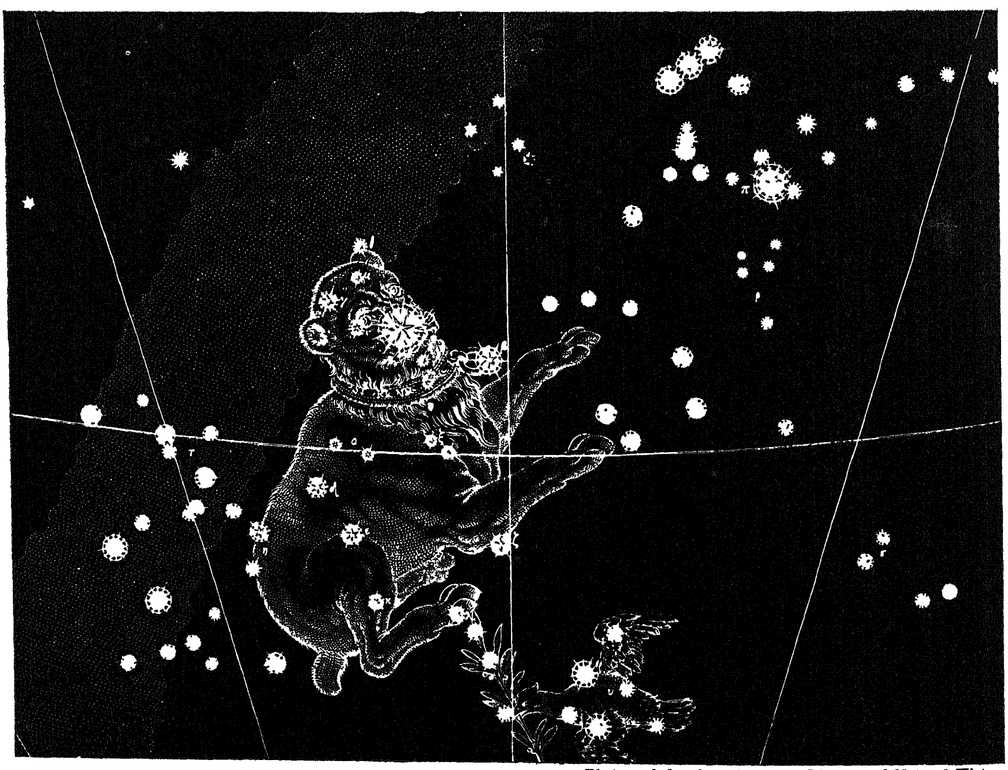


Photo and drawing, American Museum of Natural History

The above drawing represents Canis Major, the Big Dog. The large star in the dog's nose is Sirius.

THE GROUPING OF STARS

The Drawing Together of Suns in Doubles, and Double-Doubles, and Unexplained Clusters

NEW WONDERS SEEN WITH THE FIELD-GLASS

THERE are in the heavens a great number of stars which look single to the unaided vision, but when studied with the help of a good telescope are found to consist of two separate companions whose destinies are permanently linked together. These wedded stars are of great variety and of extraordinary interest.

Not all the pairs which appear so at first sight are really united in this way. With the increasing power of modern instruments the discovery of "double stars", as they are called, has proceeded rapidly; but at the same time many stars which appeared in smaller telescopes to be in extremely close proximity have been shown by these great magnifiers to be at considerable distances from one another, so that their apparent union was perhaps no more than an optical effect. Yet the occurrence of two stars really close to one another is far too frequent to be merely accidental or merely optical, and further observation of these remarkable couples has established beyond all doubt the fact of real physical proximity and interaction in many of them: when such a physical relation exists the double star is called a binary star or simply a binary. It is probable that the great majority of couples will eventually be proved to be true binaries and hence indissolubly united. With the exception of one or two cases these pairs of stars present and will continue to present to the unaided eye but a single point of light; for being bound together by the force of gravitation they can never be separated or pursue independent paths.

Such double stars represent a state of things notably different from the single dominion of our sun in the solar system; they consist of two suns, mutually circling about one another, and possibly themselves the center of an unseen system of planets, though this is scarcely probable; for how planets would perform their orbital movements around two bodies thus mutually revolving is very difficult to imagine, and presents mathematical questions of great complexity. Whether, in such a system, each sun would have its own set of planets, small enough and near enough to be practically undisturbed by the other, or whether the planets of a binary system would perform complex movements at a considerable distance about the two bodies at once, or whether they might be subject to some sort of alternating attraction, are questions we cannot answer as yet.

All that we know at present is that these binary systems of two mutually revolving suns are extremely numerous in the heavens; indeed, it is possible that at least one star in five or six, and perhaps even a larger proportion, is of this nature. The majority of couples, however, are much too close together to be divided by any telescope, and we only know that they are binaries by means of the spectroscope. The list of telescopic binaries known to be in actual revolution contains many hundreds of stars, and besides these many thousands of couples consist of members so close together as to have between them only an angular distance of one second or less; and in many other cases where the distance between the pair is greater than

this there are proofs of real systemic relation hardly less conclusive than an ascertained mutual revolution would be.

Physical agreement forms a strong proof of real affinity between the members of an apparent couple. When two stars which are very close together in a telescopic view of the heavens present a striking similarity or contrast or harmony in colors, it may usually be concluded that they are physically united — that is to say, that they form a single system, and are in mutual revolution. This assurance is greatly strengthened when the two stars are found to undergo simultaneous or regularly alternating changes in color. For example, both Antares, the chief star in Scorpio, and also the chief star in Hercules, are deep red stars, the first with a sea-green, the second with an emerald-green companion. This combination was in each case sufficient in itself to convince astronomers of the existence of a physical relation between the red and the green star, and the companion stars have since turned out to be in both cases in mutual though extremely slow revolution.

Relationships of stars are those probably based on physical affinities

Other cases of colored pairs known to revolve around one another have been found in the constellations of Cassiopeia, Boötes, Cepheus and Cygnus; and it is regarded as probable that physical affinity will be found to underlie the color harmonies of all pairs in close proximity to one another. Some doubt has been thrown on the existence of such real relationship in several particular cases, but no conclusive evidence is as yet forthcoming with regard to these.

Similarly, two stars close together which undergo light-changes in concert or in regular alternation may be taken to be really in union with one another; either both brighten together, or one becomes brighter and the other duller, and then the position is reversed. It is very unusual, although one possible example in the constellation Cygnus is known, for only one star of a binary system to vary while the other remains constant.

The crowning proof of real physical union in double stars is, however, the evidence of orbital motion. Stars which can be ascertained to revolve round one another are unquestionably related as the members of an indissoluble system — indissoluble, that is to say, in the ordinary sense, for, of course, some catastrophe from outside might break up the system.

The big difficulty of measuring orbital movements at immense distances

The discovery of these orbital movements has opened up a possible avenue to a great wealth of information concerning the stars. If once the relative movements of double stars could be measured, their masses in proportion to one another could be ascertained, and much would thereby be learned as to their light-giving qualities. But the difficulties in the way, except in relatively very few cases, are at present well-nigh insuperable.

In the first place, the actual records of relative movement are liable to enormous error, for a displacement which is hardly observable even in the largest telescope represents a real motion through thousands of millions of miles. An entire orbit, occupying in some cases a computed period of thousands of years for its fulfilment, would trace out for us, if projected upon the heavens, an extremely small ellipse, even if it could be followed by the most powerful instrument. The application of photography has in certain cases, however, solved most of the difficulty arising from the probability of error. Where the component stars of a binary system are far enough apart and sufficiently equal in brilliancy to give distinct images on a plate, photographic records at regular intervals ought in time to provide a complete record of the mutual revolution of the two stars, and records of this kind could be trusted to be free from any considerable error. But the photographic method fails when the two stars form a very close pair, for in that case their images become confused on the plate; and it fails again when one star is considerably brighter than the other, for then it is impossible to obtain a distinct print of the duller star.

The difficulty of estimating the rapidity of orbital movement

It remains possible, however, to investigate by means of photography all stellar orbits in which the binaries are of fairly equal brilliancy, and at a distance of one second of arc.

In 1919 a new era in the measurement of extremely small angles was inaugurated by the development of the interferometer method which had been first suggested by Fizeau in 1868 and tried by Stéphan in 1874. It was then abandoned for many years until Michelson once more took up the method, in 1890, developed it very thoroughly from the theoretical point of view and applied it to the measurement of Jupiter's satellites. Very little use was made of these researches until thirty years later when a modification of the method, suggested by Michelson and carried out by Messrs. Pease and Anderson of the Mt. Wilson Observatory, enabled the latter to measure the minute varying distance between the two components of the close binary star Capella and thus determine their combined orbit with a degree of accuracy surpassing anything obtained by previous methods.

However, even when accurate measures have been obtained by these or other methods, great difficulties still remain in the way of a complete solution of the problem. For the orbit of a binary star thus secured gives us, not two distinct figures tracing the individual real paths of the two stars, but one composite ellipse representing the successive mutual positions of the stars, and made up, therefore, of the combined real movements of the two. It could only give the actual movements if one body were perpetually at rest and the other moved around it. But this, as we know, is never the case. Influence is always mutual, the amount of motion produced in each of the two bodies varying inversely as its mass. In every system whatever, *all* the bodies are in motion, each performing movements corresponding in kind to those which it produces in others; but the extent and rapidity of the movements of each depend upon its relative mass. Thus, our sun itself moves in an orbit similar in form to the orbit of each of the planets, but very many times smaller. In binary systems the two stars, though often unequal, have never anything like the inequality which exists between our sun and even the largest planet, so that the resultant ellipse showing the mutual revolutions of the two stars does not even approximately show the amount of movement of either star, though it does represent the shape of the orbit pursued by each. In binary systems the two stars revolve round one another in orbits of exactly similar form and are always at diametrically opposite points in these orbits — that is to say, at either end of a straight line drawn through their common focus. But to dissever the motions of the two is a task of extreme difficulty and most laborious; and up to the present there are only a few cases in which it has been possible to determine these motions with any considerable degree of certainty.

The double star Gamma Virginis consists of two third-magnitude stars. These two stars fluctuate alternately in light, each in turn losing about half a magnitude. They perform a complete revolution about one another in 182 years, and it has been computed that the real orbits of the two are equal and in the form of a much elongated ellipse. These two stars are therefore of equal masses.

The most convenient of double stars for studying orbital revolutions

The chief star in Centaurus, a southern constellation, is one of the three brightest stars in the whole heavens, and was discovered to be double by the Jesuit missionary Jean Richard during his observations of a comet in 1689. It is nearer to us than any other double star, and this makes it specially valuable for purposes of observation. The component stars are seen much further apart than usual, being separated by eighteen seconds of arc. The real distance between the Centaurus pair is over twenty-three times the distance between the sun and the earth, or about one and a fifth times the distance between Uranus and the sun. This dis-

tance is considerably exceeded in the case of 61 Cygni and still other binaries are known to be actually more widely separated than the Centaurus stars, but we can never see them so. The facts that both the component stars are exceedingly bright, that they are distinctly separate, and that they are near enough to us for their distance to be ascertained, make this pair not only much easier to observe than most others, but also much more productive of real results. Moreover, they have been under observation for a considerable length of time. The period of revolution in this system is about 79 years, and the combined orbit is an ellipse not nearly so much elongated as that of the double star in Virgo. The combined mass of the two stars is twice that of the sun, the brighter component containing one and one-seventh as much matter as the sun and the less bright six-sevenths of the same. The masses of the two stars are thus fairly equal, but the brighter of the two gives three and a half times as much light as its companion.

This is one of the few double stars near enough to the earth for its distance to be ascertained. This distance is such that light would take four years and four months to traverse it — that is, it is more than two hundred and eighty thousand times the distance between the sun and the earth.

The extraordinary double character of the brilliant star Sirius

In his book entitled "The Binary Stars", R. G. Aitken, whose work at the Lick Observatory has made him the leading authority on this subject, lists fourteen double stars which have been measured successfully, and with some real precision with regard to distance, orbital movements and masses. Alpha Centauri, the binary just described, is one of these. Sirius is another, but it has not been known as a binary for anything like as long. It was in 1844 that Bessel, when studying the movement of Sirius in the heavens, found traces of the influence of an unseen satellite in regular periodic undulations in the star's motion. The disturbing body itself was discovered in 1862 by Alvan G. Clark at Cambridge.

It forms an astonishing contrast with the glorious white luminary which it influences. It is of a dull yellow color, of about the eighth magnitude and gives less than one 10-thousandth of the light of the brighter component; yet the mass of this dusky insignificant star is found to be very considerable, being in fact, almost one-third that of Sirius itself, the two together making up a mass three and a third times that of the sun.

The balancing of the companion stars of Sirius on their center of gravity

Sirius is distant from us about fifty million millions of miles, and the two stars of the system rotate in a period of 49.3 years. The orbit is considerably eccentric, more so than that of Alpha Centauri, but not nearly so much so as that of the double star in the Virgin. The two stars are separated by a mean distance of twenty times the distance between the sun and the earth, and perform similar orbits of very unequal sizes, but are invariably diametrically opposite to one another, exactly as in the case of doubles pursuing equal orbits. The orbits may be represented diagrammatically by two intersecting rings of exactly similar form but of different sizes, and having the major axis of both in the same straight line. Along the path of Sirius through space, the center of gravity of the whole system moves undisturbed in a direct course, the two stars being always at distances from it in a certain unvarying ratio to one another, corresponding to their respective masses.

The first double star to be discovered was Mizar, so called by the Arabians, one of the chief stars in the Great Bear, or the middle star in the handle of the Big Dipper. As early as 1650 it was known that Mizar consisted of two stars, of the third and fourth magnitude respectively. These stars are far enough apart to be seen distinct from one another in a moderately strong telescope. Their orbit has a very long period: its exact value cannot be determined but it is probably several thousand years. This system is of unusual interest on account of other stars which are involved in it.

Another pair easily resolvable in a good telescope is the brilliant star Castor, illustrated on page 4004, in the constellation Gemini, consisting of two bright white stars tinged slightly with green, one of the second, the other of the third magnitude. These two stars revolve in a highly eccentric orbit with a period estimated at about 350 years; they are twice as far from one another at their greatest as at their least distance. Moreover, each one of the pair is itself a spectroscopic binary so that we have four suns united in one physical system.

Double stars that take centuries to travel their orbit

The largest known orbital movement in a strictly binary star is the path of the pair known as 61 Cygni. The mean radius or half the major axis of the ellipse in which the companion star moves around the other component is computed to be almost ninety times the distance between the earth and the sun. This enormous path requires at least several centuries for its fulfilment: owing to the slow revolution of the pair its orbit cannot be determined with any exactitude as yet. The longer the period of an orbit is, the more protracted must be the series of observations required for its determination. Thus in Aitken's list of sixty-eight binary systems for which the computed orbits are considered as fairly reliable, thirty have periods of less than fifty years; and fifty altogether, including the above thirty, have periods of less than one hundred years. The shortest known period for a visual binary is that of Delta Equulei which completes its revolution in 5.7 years: we have no means of telling what is the longest period, but for some of the slow-moving couples, in which traces of orbital motion are hardly discernible, periods on such a scale as twenty thousand years have been tentatively assigned.

All the stars which we have so far been discussing excepting Capella are clearly of a double nature when they are observed in the great telescopes. But many are known to be true binaries which never can be seen, even with the most powerful instruments, as anything but single points of light. They are either too distant, or too close together, to be separated to our view. Yet their double nature is indubitably revealed to us by the spectroscope.

Stars known as compound, though the largest telescopes will not separate them

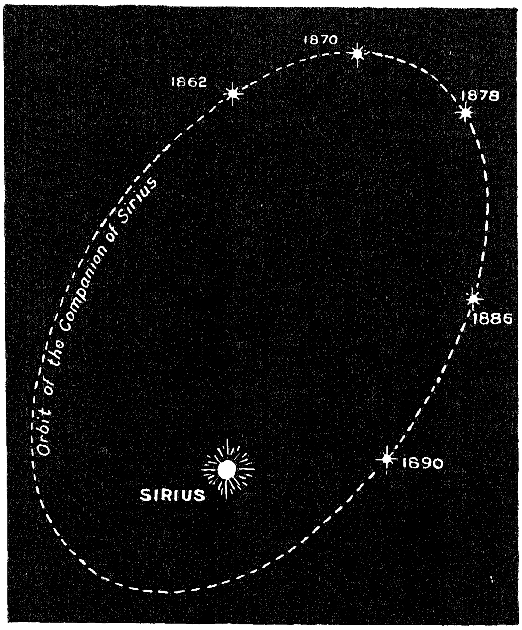
Stars which appear single in the largest telescopes may be known, from changes in their spectra, to be compound. These changes consist in regular periodic shiftings of the lines of the spectra to right and left across their normal position — or, rather, across an average position which is not exactly the normal on account of a constant movement of the double star either towards or away from our solar system.

Just as the pitch of a sounding body is raised if it be approaching the hearer, so will the spectrum-lines of an approaching luminous body be shifted towards the violet in proportion to the speed of approach; and, conversely, if the source of light be receding from the observer, the lines of its spectrum are shifted towards the red. If, therefore, a star be moving in an orbit, and the plane of that orbit be more or less in the line of vision, it is alternately approaching and receding from the earth, and the lines of its spectrum must shift alternately towards the violet and towards the red ends of the spectrum. If two bright stars be in mutual revolution, the spectral lines appear double at two points in each revolution — namely, when the component stars are furthest apart as seen by us, and one of them is receding from us and the other is approaching us.

How we see in the spectroscope what can never be seen in the heavens

The lines due to one star are moved along towards the violet by its motion toward us, and the lines due to the companion star are displaced toward the red by its motion away from us. But at other points in their orbital revolution, when the stars are moving across the line of vision, one to the right and the other to the left, and neither is approaching us nor receding from us, the lines of their spectra are no longer double, but coincide. Thus the completion of one

revolution is measured in the spectroscope by two doublings of the spectral lines and two returns to a single set of lines. If, however, one of the two bodies be dark, it cannot reveal its presence directly by lines in the spectrum, but its existence may be detected by the evidence of orbital motion in the spectrum of the bright star. This is shown by the same shiftings of the lines, from their normal position, towards the red and towards the violet; but in this case there is, of course, no doubling of the lines. The spectral lines are displaced first to one side and then to the other, the course of an entire orbital revolution being marked by one complete swing in the two directions. Thus the spectra of stars reveal to us not only their double nature, but also the length of time taken in accomplishing their orbital revolutions. It is found that the period of revolution for spectroscopic binaries is in general very much shorter than for visual binaries: the shortest known period is that of Gamma Ursæ Minoris which completes its orbit in 2 hours and 37 minutes, and many others have periods of a few weeks or months.



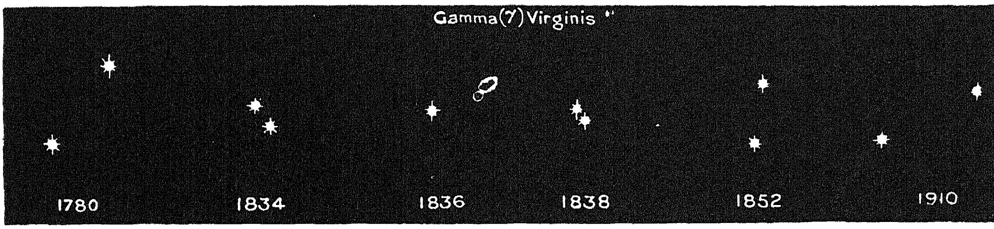
THE ORBIT OF SIRIUS'S COMPANION
This diagram shows the orbit as it appears from the earth, and the position of the companion star in several successive years.

The spectroscopic study of double stars has brought out many interesting and significant facts. For instance, in the case of colored pairs showing changes in color, the spectra have several times been found to register, apparently, not present but former conditions. Or, rather, it may be suggested that they register a more permanent and fundamental condition, while present colors are produced by more temporary and superficial conditions. For example, in the case of the two companions forming the star 95 Herculis, which have frequently been recorded as appearing green and red, but are now both primrose yellow, the two spectra are now not alike but different, one being of the Sirian and the other of the solar type. We can hardly avoid the conclusion that the Sirian spectrum is that of the former green star, and the solar spectrum that of the former red star, and it seems likely these colors will again recur in the two stars which compose this pair. Other similar examples are on record.

Capella is a most interesting star. Down to the year 1899 it was regarded as the model solar star, presenting a close analogy with our own sun; and spectroscopic observations only confirmed that impression, for no indications could be found of any constitutional difference from the sun. With the greatly improved instruments at Lick Observatory, however, many fresh details came out in the spectrum, which was soon discovered to be of a compound nature, and to bear unmistakable traces of shifting movements towards the red and the violet. Capella became the subject of engrossing investigation, and the knowledge of its double nature overturned what had been supposed to be its perfectly established character as the counterpart of our sun. It was found to be a binary system composed of two stars about equal in mass but giving spectra of unequal brilliancy. One of these stars shows a true solar spectrum, the other a spectrum intermediate between the solar and Sirian types. The latter spectrum is much the fainter, being of not more than half the brilliancy of that of the solar star.

Anderson's measurements with the interferometer showed that the visual brightness of the two components is very nearly equal. The system of Capella is near enough to us for its distance to be determined with a strong presumption of accuracy. It is estimated at a little over forty light-years — that is to say, a distance which light would take forty years to travel. These two stars circulate round one another at a distance somewhat less than that of the earth from the sun, and the plane of their orbit is calculated, from the spectroscopic observation, to lie at an angle of sixty degrees to the line of sight.

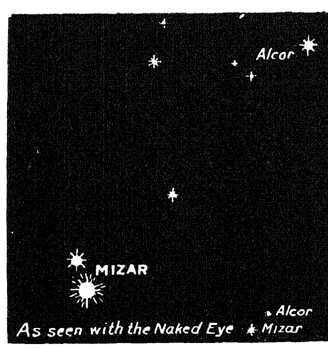
As we have already noted when considering short-period, variable stars, there are a large number of binary systems consisting of one bright and one dark member. The dark member reveals itself by periodically eclipsing its bright companion in variables of the Algol type. The study of double stars tends to support the conjecture that dark bodies are extremely numerous in the heavens and are very frequently associated with bright stars. As the motions of the stars come under more accurate observation, the influence of unseen bodies is more and more largely discovered. Occasionally the position and movements of such bodies can be conjecturally determined; and those determinations have been triumphantly established in the cases of Sirius and Procyon, the greater and lesser Dog Stars, by the discovery of very dully luminous satellite bodies in the positions indicated by mathematical calculation.



THE VARIED APPEARANCES OF THE DOUBLE STAR GAMMA VIRGINIS IN THE COURSE OF 130 YEARS
These two stars perform a complete revolution round each other in a period of 180 years Their orbits appear to take the form of an elongated ellipse. A remarkable circumstance was their coming together in the line of sight in the year 1836.

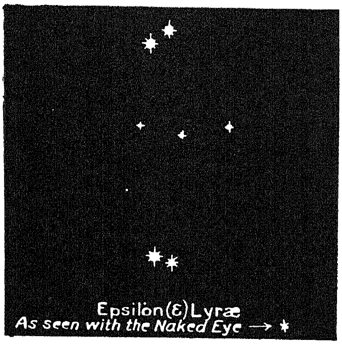
As is only to be expected, the searching observation of binary systems discloses a more and more complex variety of relations. Thus, Castor, as was noted above, is really a system of at least four stars, and our familiar Pole Star has two dark companions besides its bright one. Systems of three or four suns, or even a larger number, in related movement with one another, are being discovered in increasing numbers. The relations of such stars present a great range of variety; they are of immense interest, and give us a conception of vast movements and of tremendous rhythm and order beyond all analysis.

The relation of three or four stars in a single system is not ever, so far as has been made out at present, of the same nature as the relations of the planets in the solar system — that is to say, there are not two or three bodies revolving with similar motions around a central body. In the stellar systems we always find either two stars revolving about one another and pursuing at the same time an orbit around a central star, or two central stars in mutual revolution with a subordinate star circling round them; or, again, we get two doubles united in a common systemic motion. A system of immeasurable vastness and majesty is revealed in the motions of the star known as Epsilon Lyræ. To the naked eye this system appears as a single fourth-magnitude star; but a three-inch telescope suffices to show us all the four component stars, in two pairs, each pair being in mutual revolution in itself, and the two pairs performing a vast orbital



MIZAR, THE DOUBLE STAR IN THE TAIL OF THE GREAT BEAR

movement around one another. None of these orbits can be even conjecturally measured with any precision; the period of one pair is estimated roughly at about one thousand years, and of the other at about two thousand years; while the orbital motion of the whole system is beyond all attempts at the roughest estimation. Yet the evidence of the reality of these complex systemic movements of the entire system is indisputable. The two pairs not only have each real movements of their own; they are also in common harmonious motion through stellar space, though this motion, as we see it, amounts only to nine seconds in a hundred years.

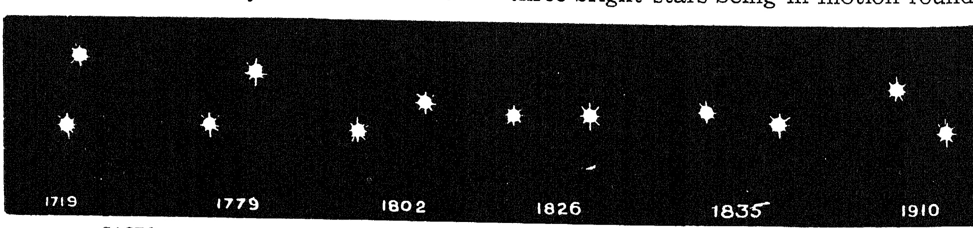


EPSILON LYRÆ
An example of two binaries revolving round a common center of attraction. The three small stars lie far beyond.

This wonderful system is not singular in the heavens. Already many such "double-doubles" are known, and it is likely that many others at present known as binaries, will be found to be of a more complex order. Aitken found at least one hundred and fifty new triple stars and estimates that about four or five per cent of all visual doubles are really triple or quadruple stars. One or two combinations of four stars deserve special notice as forming systems of a less evenly balanced kind. One of these, Mizar, in the Great Bear, has already been referred to.

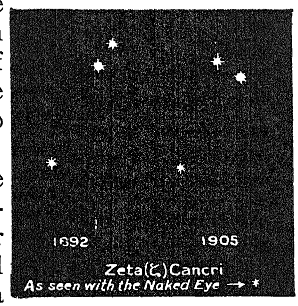
In Mizar, which is single to unaided vision, we have a telescopic double, one member of which is itself a very close spectroscopic double: its double character was discovered by E. C. Pickering at Harvard in 1889, and it is the first known spectroscopic binary. In some sort of relation to this close group, but at a distance sufficient to divide them even to the naked eye, is the star Alcor. If, as is probable, though not quite certain, Alcor is actually dependent upon Mizar, we have here a very interesting system, consisting of a primary star, with a dependant inseparable from it by the telescope, another closely united to them but distinguishable from them by the telescope, and a third (which is also a spectroscopic binary) united to the others by physical relations but by no means in very close proximity.

There is a system in the constellation of Cancer which is even more interesting. This star, Zeta Cancri, already known as a double, was discovered by Herschel, in 1781, to be of triple character, the smaller and more remote body having a movement around the closer pair, covering about half a degree in the course of a year. But certain regular variations in its motion convinced Otto Struve that this smaller star was itself in relation with a greater invisible body, around which it was circling. This has been proved by Seeliger to be actually the case. Most interesting of all is the suggestion that this dark body is itself the center of the whole system, the three bright stars being in motion round it and two of them at the same time in revolution round one another. Miss Clerke saw in Zeta Cancri, a possible example of an anti-Copernican system. "Here a cool, dark globe, clothed possibly with the vegetation appropriate to those strange climes, and plentifully stocked, it may be, with living things, is waited on, for the



CASTOR, THE BRIGHTEST STAR IN GEMINI, ONE OF THE BEST KNOWN BINARIES
These two stars, which can be easily separated with the help of a small telescope, revolve around each other in an orbit with a period of three or more centuries, while each of the two is itself a short-period binary system. The more rapid pair completes its revolution in three and the other in nine days.

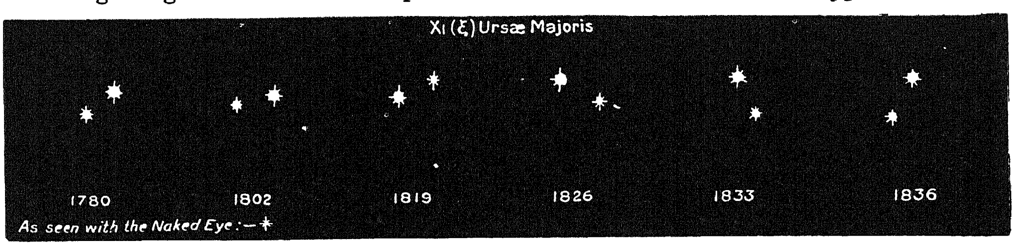
supply of their needs, by three vagrant suns, the motions of which it controls, while maintaining the dignity of its own comparative rest, or, rather, of its lesser degree of movement. For the preponderance of this unseen body cannot approach that of a sun over its planets; hence its central position is by no means undisturbed."



THE TRIPLE STAR OF ZETA CANCRI AT TWO DATES

When color-variations are also found in systems of multiple stars the effect is further heightened. Some beautiful examples occur. In Andromeda is a chrome-yellow star of slightly less than the second magnitude, with a companion of the fifth magnitude sea-green in color. But this companion, when observed in a good telescope, is found to be itself a double star, consisting of a green and a blue component.

some of the vexed questions of astrophysics. Already their evidence seems to support the reversal of the theory, formerly quite common, that development proceeds more slowly in a larger than in a smaller body. In the double star in the Virgin, the components of which are equal, the spectra of both are of Sirian type, and exactly similar. Hence they may be taken to have proceeded at equal rates in their development. In the case of a good many other bright doubles, the spectra are found to be closely matched; thus, the star Castor consists of two stars of Sirian type, and the same are found in a bright double star in Auriga, and again in Mizar. In many other unequal couples, the spectrum of the larger star is of solar and that of the smaller is of Sirian type, as in Beta



XI URSÆ MAJORIS, A DOUBLE STAR IN ONE OF THE FEET OF THE GREAT BEAR

This star was the first calculated binary, and performs its revolution in sixty years. The alteration in their relative positions during the complete cycle which led to their discovery as forming a binary is here shown.

A swiftly moving group of three stars, the chief of which is between the fourth and fifth magnitudes, is found in the constellation Eridanus. The small double star which is attached to the chief star is so distant that their real union might be doubted but for the evidence of the movement of the three in swift and equal motion across the sky. The satellites are at a distance of eighty-three seconds from their primary, and revolve about one another in 180 years.

THE BEAUTIFUL MULTIPLE STAR IN ORION

Star-couples may be presumed to be of equal age; therefore the relations which they show between size and physical condition as recorded in their spectra are of great interest as likely to throw light on

Cygni, in Gamma Andromedæ and in Gamma Delphini; or, again, the larger is of Antarian type and the smaller of Sirian type, or in some cases, as in Procyon, midway between solar and Sirian. According to the theory that Antarian stars evolve into Sirian stars through the intermediate solar type, the examples above cited would indicate that mass accelerates development. But there are examples which appear to indicate just the opposite tendency. There are a considerable number of yellow stars, giving spectra of solar type, which have smaller companion bodies of a purple or rosy-violet color, giving a vastly smaller proportion of light. The exact meaning of

the color of these satellites has not yet been discovered, but it is assumed by many astronomers that this dull, rosy glow is the sign of old age, and that the bodies in which it appears are both greatly condensed and subject to considerable absorption of light. In these cases, the smaller body would seem to have proceeded much further than the larger — that is to say, that, being of equal age, it has developed more quickly. It is just possible, however, that these dim, deeply colored satellites may prove, after all, to be of greater mass than their yellow solar primaries; and much more investigation is required before any definite conclusions can be drawn.

From the relation of two or more individual stars in a system, we pass to a system of two knots or groups of stars, an example of which is to be found in Orion. This is a third magnitude star near the middle star of Orion's belt, and is easily seen to be double with quite a small telescope. In 1779 Herschel observed it to be triple, and since then repeated observations have divided each component into an increasing number of stars. Another group of stars forming a multiple system is also found in Orion, and a similar one in a nebula in the same region. The nebulous nature of the whole realm of Orion is well known, and the prevalence of multiple stars or incipient star-clusters within it is a subject of interesting speculation among astronomers. It is believed by some that such multiple stars represent the advance-guard of the rising of a great cluster from out of the nebulous mass; while others surmise that the nebulous matter is proceeding out from the stars, as the coronal matter is thought to radiate out from our sun.

CHOICE AND CARE OF FABRICS

Tests That Show Whether Materials
Are What They Are Claimed To Be

HOW TO RECOGNIZE FIBERS, QUALITY AND VALUE

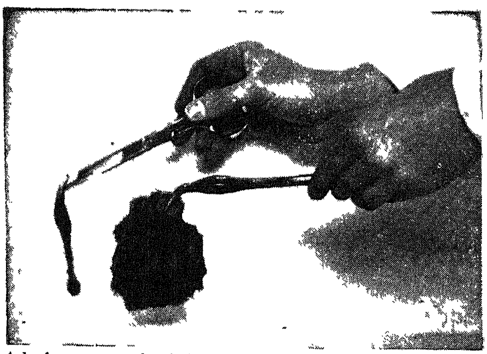
A GIVEN piece of material may be sold as cotton, linen, wool, silk, rayon, or nylon, or a mixture of these fibers, but every purchaser as well as the salesman should be able to confirm the statement on the label. Not only is a qualitative estimate of importance to avoid deception, to judge of the probable wearing qualities of the material, to estimate its monetary value, and to know what treatment it can safely undergo in the cleansing processes, but a rough quantitative estimate will be of use particularly in valuing it; and an examination for possible flaws or defects in weaving, for short fibers in the yarn, and for the presence of dressings which will cover up such flaws and, in the case of silks, for "weighting" which will affect the wearing qualities, will be of the greatest value. Unfortunately, many of the trade names under which materials are sold are misleading. Flannelette is not a modified flannel, but is cotton made to have somewhat the appearance of flannel. Rayon, formerly known as artificial silk, is made from cellulose (woody fiber or cotton) which is so treated that it has a silky sheen. Cotton fabric is sometimes treated to make it look like linen. Cheaper fibers may be used with better ones, yet hidden by them, and the price is usually in no way a criterion for quality.

The question arises as to whether such treatment as making one fiber look like another, or of mixing a cheaper fiber with a more expensive one, or of "re-working" wool, is desirable. It depends. Cotton mixed with wool makes the material shrink less in washing, therefore may be desirable in some fabrics, though such a mixed fabric will not give the same warmth as a pure wool one. Cotton mixed with wool makes a cheaper material than the all-wool fabric could possibly be, and yet the mixture is warmer than cotton alone. It also brings the price of a "woolly" material within reach of the poorer members of the community. The re-working of wool makes the supply of wool goods greater, and with care and discrimination in preparation, and by mixing with it a certain proportion of virgin wool, the wearing quality of the material will approach very nearly that of the virgin wool, but its price should be less. It must be remembered that if all the wool produced in the world were evenly distributed among the inhabitants outside the tropical regions, each individual would get only about fourteen ounces each year and the price of pure wool would be greater than that of silk. Silk is a very expensive fiber, and unless imitations were made, and unless silk other than that produced by the cultivated silkworm were used, a silk garment would be so expensive that it would have to be worn, as it was a century ago, for a much longer period than is compatible with the swiftly changing fashions of today.

The use of substitutes and imitations is therefore legitimate for certain purposes and no objection can be raised, on the whole, if the fabrics are described correctly and priced accordingly. When fabrics are standardized as carefully as are the food products on the market today, there will not be the same need for the purchaser to know how to recognize the fibers as there now is, or the same need to look for flaws, dressings and weightings.

The fibers commonly used for the manufacture of ordinary fabrics

The fibers commonly used for the manufacture of fabrics today can be divided into three classes: (1) fibers of animal origin (wool and silk), (2) fibers of vegetable origin (cotton and linen), (3) synthetic fibers (rayon and nylon). The characteristic appearance and feel of these fibers is distinct, and by handling samples of the pure threads and materials a knowledge of them can be acquired much more easily and perfectly than from any verbal description. Pieces of standard materials should be studied for appearance, feel, weight, finish, and comparative costs, so that the fabric under consideration can be compared with these. A piece of the yarn from the warp and the weft of the material should be separated and untwisted. This will show that the yarn is made by twisting together a number of fibers which vary in length according to their nature. The average length of cotton fibers is from three-quarters of an inch to nearly two inches. If unusually short fibers are twisted together to form the yarn, the tensile strength will be reduced and fabrics made with such yarn will probably be damaged very quickly by laundering and use. The better quality materials are made from the longer fibers, the shorter ones having been removed in the combing and carding processes. Linen fibers are much longer and consequently when spun together make a stronger yarn than cotton. They have also a much greater luster. Wool fibers vary from two to twenty inches in length, the short duller staples being used for soft, loosely twisted, "woolen" materials, while the longer and more lustrous ones are used for closly twisted yarns to make serges, covert cloths, "worsted" suitings, etc Silk fibers are very long, glossy, and elastic. When spun by the silkworm, the length of the fiber may be anything up to fifteen hundred yards; and not only are these great lengths twisted together to make a thread, but the short, broken pieces from the outside and inside of the cocoon and short lengths from spoiled cocoons are also twisted or spun together to make a yarn which, although pure silk, will not have the same strength as the yarn from the long fibers. Silk from the uncultivated silkworm is not so fine, white or lustrous as that from the cultivated worms.



Ash from unweighted (left) and weighted (right) silk when allowed to burn in air

Rayon and nylon are comparatively new fibers but are used extensively. Their popularity, no doubt, comes from the fact that they are synthetic fibers created in a laboratory as a result of years of research to satisfy consumer demands and expectations. Their production is not limited as other fibers are. The raw products used in their manufacture are vastly abundant. The cost is made moderate by this factor, which in turn is a result of greatly increased volume.

Rayon is made of a chemically treated cellulose derived from wood pulp and cotton linters which form a viscous solution. It becomes a fiber by several processes. The solution is forced through the minute holes of a spinneret and comes out a filament. It is dried and hardened by means of air or a chemical bath. There are three methods of rayon manufacture: (1) cuprammonium, (2) viscose, and (3) cellulose-acetate. Each derives its name from an important step in the process and produces a type that has different characteristics and consequently contributes to its versatility. Although its creators were trying to make silk artificially, they discovered a new fiber more versatile than any natural one, producing effects not possible with other fibers.

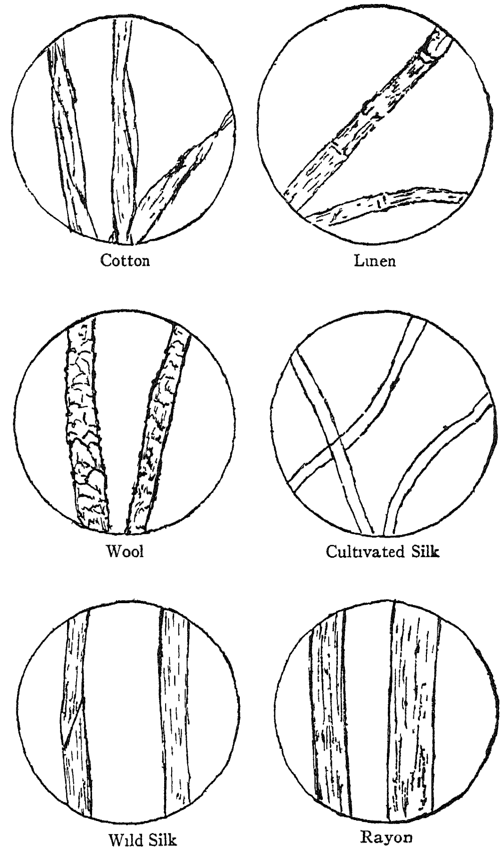
Nylon is a plastic derived from coal,

air, and water treated by a complex series of chemical reactions. A tough, white material is obtained which is melted and forced through the minute holes of a spinneret and forms continuous filaments (similar to rayon). Nylon is adapted for fashioning into filaments of extreme toughness, strength, and elasticity. It is widely used in hosiery, bristles, and sheets.

Two kinds of fibers may be spun together, or woven together, and the examination of the threads from the warp and the weft of the material will indicate whether one or more kinds of fibers have been used in the spinning and weaving.

Not only can the fibers be identified by their appearance and feel, as indicated above, but they burn with characteristic differences. The animal fibers burn slowly -- wool much slower than silk and with a more disagreeable odor. Wool leaves a crisp black residue; silk, a very little black ash, unless weighted with metal compounds, when a white or gray residue retaining the shape of the original material is left (see illustration). The vegetable fibers burn quickly and with practically no odor, and leave a very little white ash. In a mixed fabric, the presence of the odor of burning wool does not, however, mean the absence of cotton or linen, although the absence of smell must necessarily mean the absence of wool or silk.

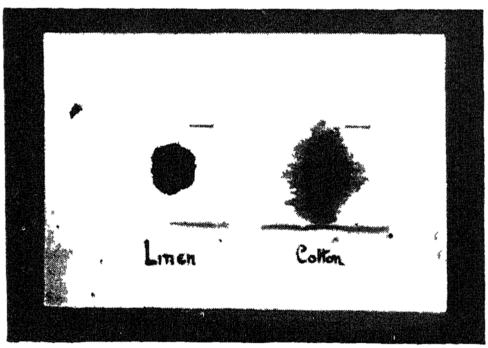
If one has a microscope, this is the quickest and surest method of identifying fibers, for they have very characteristic appearances, as illustrated on this page. In fact, the microscope is the only *sure* method of differentiating linen and cotton. Both are cellulose materials and react similarly with chemicals, particularly if bleached, though there are some slight differences in other ways which can be looked for. If the linen is unbleached or only partly bleached, it will become decidedly yellow in the lye solution. If, however, it is fully bleached, there is little or no difference between it and cotton. If a drop of water or ink be placed on pure linen or pure cotton, there is a difference in the behavior of the drop, dependent on the material; the liquid seems to stand on the surface of the cotton for a few seconds and then spreads rather far in all directions, while on the linen it sinks in at once and forms a more concentrated and compact stain (see next page). On a mixed cotton and linen fabric this test fails, as does also the oil test. Oil dropped on pure linen, however, makes a translucent spot while on pure cotton it makes an opaque spot.



TEXTILE FIBERS: MICROSCOPIC APPEARANCE

The proportions in which wool and cotton are mixed, and whether they are spun or woven together in any fabric, and the pattern of the weave, is indicated by boiling the fabric in lye, when the wool will be destroyed and leave the cotton (see page 1905, 1–4). If the mixture is silk and cotton, or silk and wool, the silk can be removed by treating with muriatic acid for a few moments and then rinsing (see page 1905, 5 and 6).

In choosing and identifying fabrics, it is well to know what possible deceptions and sophistications may be practiced. Cotton may be made to look like linen by using a rather unevenly spun thread, by using a "linen" weave, and by beetling and calendering; and to have a silk finish by mercerizing. A so-called "linen" may be a mixture of linen and cotton. A poor quality cloth may have a heavy dressing which will disappear in the first laundering and leave a thin, sleazy material with possibly several flaws in it, such as loose or broken threads, or other injuries due to carelessness or haste in manufacture. The fabric will probably wear very quickly at such places when laundered. Silk is frequently woven with cotton one way and sold as "silk." Wild silk is sometimes



An ink-spot on linen and cotton fabrics.

used with cultivated silk and sold at the price of cultivated silk. Rayon is sold as "silk". Cultivated silk is sometimes so heavily weighted with tin compounds to give it stiffness and rustle that even without use it becomes full of holes almost at once. This is possibly owing to the crystallization of the tin and the consequent cutting of the fibers. Cotton is "plated" or "surfaced" with silk. The reason for the high cost of genuine and durable goods becomes apparent when one studies the subject

While no definite statement can be made as to the length of time that any fabric should wear, every one knows that its useful period of service is affected by three factors: (1) its quality at the time of purchase, (2) its use, (3) its treatment in the laundry.

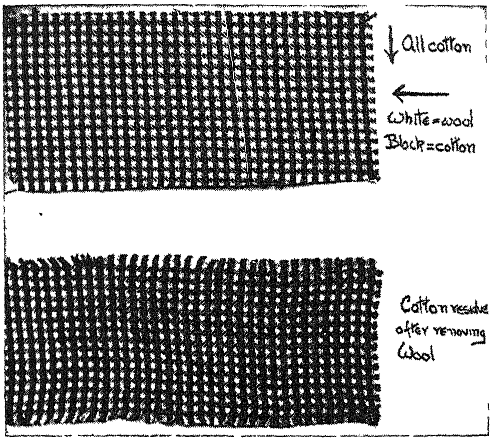
(1) For this manufacturer or dealer is, of course, responsible in the first place, but we have tried to show that the buyer should be in possession of such knowledge as will enable her to avoid deception as to the quality and composition of the cloth; to be able to detect flaws in the weaving which will cause the material to become full of holes with wearing and washing; and to be able to judge of the probable wearing qualities of the material.

(2) In the matter of use, the responsibility is purely the user's.

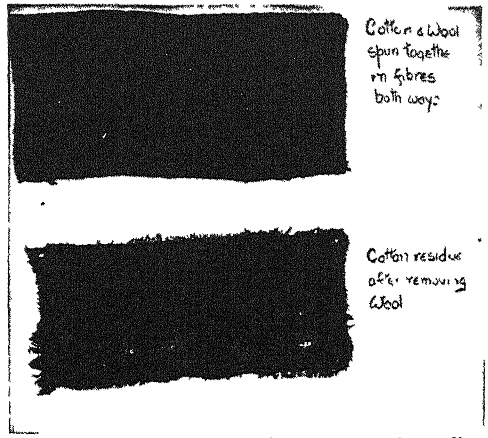
(3) We have, in the chapter on cleaning processes, shown that the proper treatment for the removal of stains is essential for the normal life of a fabric, and that the immoderate use of washing soda and other alkalies, and particularly the indiscriminate use of bleaching agents, is a large factor in the destruction and undesirable appearance of materials. It should be understood that every process in the laundry will have some effect on the fabric, but we believe that with careful and correct mechanical treatment, by the careful, correct use of stain removers and bleaching agents, and by using pure soap together with soda in the proper amount, or by replacing soda with borax or ammonia in the case of wool and silk, the destructive effects can be reduced to a minimum and the material will last a normal length of time, dependent on the initial quality and use as well as on its laundering. It will be convenient at this stage to summarize the various rules for washing clothes.

White cotton and linen goods should be soaked for some hours previous to washing, as this certainly loosens much of the dirt, removes some stains and softens starch. Cold or warm water must be used; hot water is to be avoided, as it will harden any coagulable matter present. If the water is hard, it should be softened by having one tablespoonful of washing soda dissolved in approximately ten gallons before the clothes are put in. The solid soda should on no account be thrown in on top of the clothes, as it will then form a concentrated solution in spots. A little soap may be rubbed on very soiled parts of clothing, such as cuffs, collars, etc

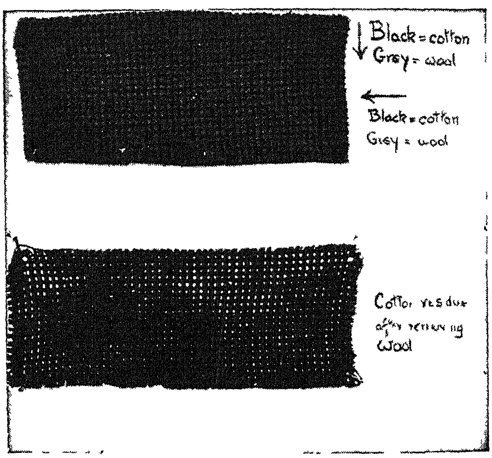
THINGS ARE SELDOM WHAT THEY SEEM



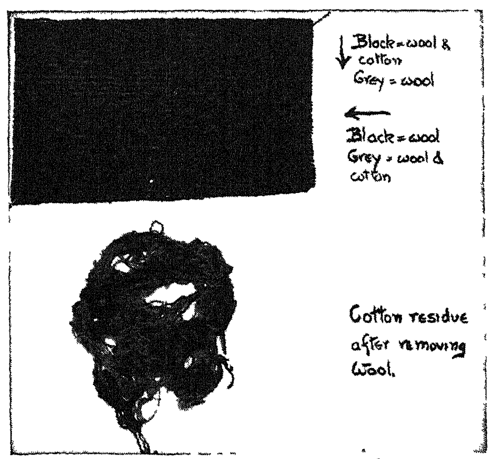
1 Cotton residue after removing wool shows that the white threads in one direction only were wool



2 In this case the cotton and wool were spun together in fibers both ways

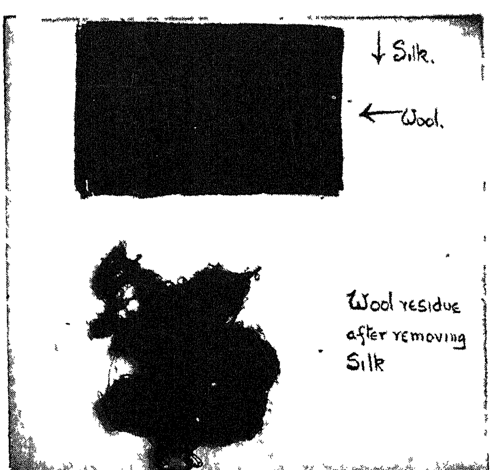


3 Here the gray threads in both directions were wool while the black were cotton.

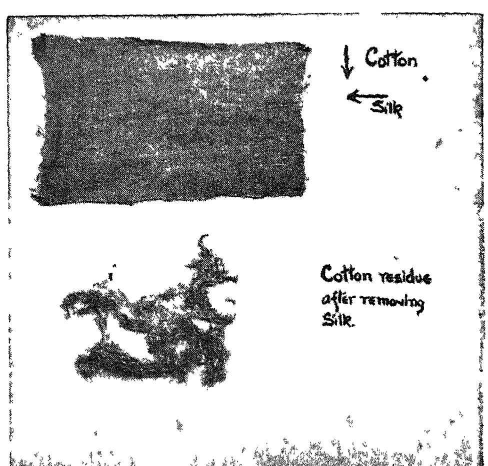


4 Some threads in both directions wool and cotton spun together, the remainder wool.

COTTON AND WOOL MIXTURES



5. Silk and wool woven together.



6 Cotton and silk woven together.

SILK AND WOOL AND SILK AND COTTON MIXTURES

After soaking, the clothes should have the dirty water wrung out of them, and then be transferred to soapy water which has been prepared, after it has been suitably softened by adding either soap jelly (made by dissolving shredded, hard soap in hot water) or soap chips, and beating it till a nice, but not too heavy lather is formed. They should be kneaded and squeezed in this until they are clean; a second bath may be required. In the washing-machine they should be treated for ten to twenty minutes as their condition requires. Gentle rubbing by the hands will help to remove dirt from the very soiled parts. Rubbing on a washboard is very destructive and should be resorted to only when absolutely necessary for the coarse fabrics.

When the clothes are thoroughly clean, they should be rinsed in clean water to remove the dirty, soapy water before being boiled, as otherwise it will be "boiled in" and the clothes will not be a good color. Neither will they be if they are not clean before they are boiled. Boiling helps to bleach clean clothes but its main purpose is to sterilize them, so that even when a washing-machine is used the clothes should be boiled occasionally. The boiler is prepared by softening the boiling water carefully and adding a little soap, but not sufficient to make a lather. It should be somewhat below boiling-point when the clothes are put in and afterwards gradually raised in temperature and allowed to boil ten to twenty minutes. The clothes should then be removed, allowed to drain a few seconds, and rinsed first in hot, then in cooler water. The use of hot water for the first rinse prevents the formation on the clothes of insoluble acid soaps which are difficult to remove.

Thorough rinsing is absolutely essential if clothes are to be white. Any soap left in them causes slight discoloration on drying. Blueing is seldom necessary if clothes have been treated in this way with a pure non-resinous soap, and if the use of "bleach" and excess soda or other alkalies has been avoided. The need becomes even less if clothes are dried in the open air and sunshine, for this helps to bleach them.

In the washing of woolens the nature and structure of the wool fiber necessitates a treatment slightly different from that to which white cottons and linens can be subjected. Reference to the fiber figure will remind the reader that that of wool is long and cylindrical, with flattened horny scales overlapping each other on the surface. When subjected to the action of *hot* water, particularly in the presence of soap or free alkali, the fibers swell, and if there is much movement and rubbing or pounding the scales interlock and the material will become felted together. As this is precisely what has to be avoided, and in order that the softness and elasticity of the material may be retained, hot water and much pounding and rubbing must be eliminated. The material must be gently kneaded and squeezed in the soapy water. Woolen clothes are best washed in *lukewarm* water which has been softened with the proper amount of borax (or, failing that, ammonia) and to which has been added some good pure soap (jelly or chips) in quantity sufficient to make a lather about one inch thick on the surface of the bath before putting in the articles. The soap should be entirely dissolved before the clothes are put in the bath. When clean (that is, after perhaps two or three soap baths), all soap must be thoroughly rinsed out and the articles should be dried in a cool atmosphere. A drying chamber is usually too warm. Woolen garments which are likely to pull out of shape should be laid on a table or on a sheet on the grass and patted into shape before being left to dry.

Blankets which are very soiled, and other wool articles, can be soaked for a short time before washing. The prolonged action of cool water does not cause felting and shrinking.

Silks which are washable should be treated in precisely the same way as wool. The use of alkali (except a little borax or ammonia) or adulterated soap is detrimental. Rubbing and twisting will pull the threads out of place, so silk should be treated very gently and the water squeezed out by hand or by a rubber wringer. A little blue may be added to the last rinsing water for white silk.

HEALTH IN CHILDHOOD

The Course of Care by which Children
Will Grow up Naturally Well and Strong

GENERAL PRINCIPLES AND SPECIAL HINTS

WITH every thing, but with living beings above all, beginnings matter immensely. The living creature has in it at any moment the whole of the individual and racial past. If we wish to secure its health we cannot begin too soon. A chapter must therefore be devoted, before this section closes, to the physical health of infancy and childhood, in the proven belief that attention to hygienic principles at these periods will be repaid at every subsequent stage of life.

In the United States the physical care of school children has already reached a great development. The work of the medical inspector at first was only to quarantine cases of acute infectious disease, segregate those exposed and close and disinfect the school if necessary. Later was instituted an examination of the eyes, ears, nose, throat and finally the teeth.

If we desire to maintain the health of a child, we should begin our task with the care of the mother-to-be as soon as it is certain that she is pregnant. We should inform her that the health of her child will depend largely upon her own health during the period of her pregnancy. A few words suffice to define her duty at this period, for herself and her child. It is very necessary that she should be happy — as happy as possible. Especially during the last three months she must avoid every kind of strain, excitement, and unrest. Social "duties" and the like must be regarded as of no moment now. The expectant mother who takes proper care during the last three months will bear her child longer; and this means that its birth will be easier for her and its chances of life much raised. But physical idleness is not desirable. Gentle, regular daily walking exercise is most important for the proper health of the body and for the tone of the muscles, and for the obtaining of good sleep.

This last point is most important, and is urgently insisted upon by all modern obstetricians. We need hardly point out that the physical and psychical difference between such exercise and hard, prolonged, compulsory, manual labor is extreme, and that the one is as good as the other is bad for the expectant mother.

During the last few weeks she will attend carefully to the invaluable organs upon which her child's chances of life will largely depend; for we know, beyond dispute, that no perfect substitute for its mother's milk can be found. When the baby is born, its eyes will be immediately and thoroughly bathed and washed out. It needs no food as yet. Twenty-four hours may elapse; and during that period the baby should receive no sugar-and-water, nor any other absurd and irrelevant concoction without the sanction of nature. Thereafter, the child should be put to the breast; and if its mother can nurse it for many months to come it will make the best possible start in life.

No child is born rickety. There is no such thing as "congenital rickets," though the phrase has been used. Nature knows better than to feed a child on what produces rickets before it is born. Every case of rickets is an *acquired* disease of malnutrition, for which someone is responsible.

It may be the mother; or some dead "statesman" who forgot to have the nation's future mothers taught the elements of living when they were at school; but someone is certainly responsible. A mother should be encouraged to nurse her child herself, thus guaranteeing it against rickets — for a long time to come, at any rate. Her vital energies have toiled for it unceasingly, day and night, for many months. She may as well complete the task to which she has already given so much of her own life. If she wishes to prevent the child's fair promise from being blighted, her first duty is to nurse it herself. Most of the prize-winners of life were fed by their mothers when they were babies, and most of the babies that do not survive are *not* fed by their mothers. Nature has been at her task of saving babies a long time, and this is the way she has found best.

Doctors have tried everything they can invent for babies instead of their mothers' milk, and the conclusion of the whole matter is that mothers' milk is best. In France, where babies are scarce, and therefore precious, doctors tried feeding them with all sorts of things, but now they feed the mothers, and the wonderful chemistry of the mother's body does the rest.

Very often the mother thinks she cannot nurse the baby, and gives up trying, and unwise nurses and even doctors may help to dissuade her, and may say that the bottle will be better. In the end they turn out to be wrong, terribly wrong, over and over again. They should rather try to give the mother rest, peace of mind, and sensible food, with plenty of milky things.

Should the mother die, or there be conditions that make nursing impossible, substitute feeding must be resorted to. Wet-nursing is no longer popular in America, owing to the possibility of the nurse bringing disease into the household, to say nothing of domestic discord. Moreover, the child of the wet-nurse is likely to die as the result of neglect or unwise feeding. Should such a nurse seem essential, she should be subjected to the tuberculin test for tuberculosis and the Wasserman test for syphilis.

The grave lack of wisdom in unnecessarily early weaning

Of all the calamities that may occur to the infant during the first week or two, by far the most serious is that of unnecessary weaning. Far too often the influence of the doctor and the nurse is thrown upon the wrong side, and it is common to find the child weaned, to its serious injury, often mortal, simply because the expectant mother has not been taught how to care for the nipples, to draw them out if they are depressed, and to prevent them from cracking.

When the mother suffers from consumption, she certainly must not nurse her baby, for that would be dangerous both to her and to it. On the other hand, the relatively trivial malady called constipation is often a cause of unnecessary weaning. If the constipation persists, the milk is apt to be affected, to the child's detriment. On the other hand, if an aperient be given, the child receives a portion of the dose, and may be upset. Therefore, the simple rule is that, by a well-chosen diet and by proper exercise during the last few months of pregnancy, the expectant mother should prevent constipation; and then it will not be so difficult to keep things right afterwards.

But psychical causes, worry and excitement, are just as inimical to the proper establishment of nursing as is constipation itself.

The effect of mental causes in preventing the nursing of infants

Even among our domestic animals we find that alarm and excitement spoil the milk; and how much more is this likely to be true of so highly organized and sensitive a being as a woman. After childbirth many women are easily upset and depressed; and though a mother may put the best face on matters during the doctor's visit, he may find on inquiry, that she has been in tears over some comparative trifle. This very common tendency towards loss of mental equilibrium has a serious influence, in many cases, upon so delicate a function as the production of nutriment for the baby.

Of course, some mothers really cannot nurse their babies and then they must utilize cow's milk. This involves some serious risks, which must be guarded against. Cleanliness is all-important, for the lack of it means the growth of millions of microbes in decayed milk, which is an admirable medium for their growth. In Manchester it was noted that the death curve of diarrhœa in infants corresponded closely to the prevalence of flies. Another study showed that the death-rate rose as the wages fell, which means more crowding of persons in small rooms. The death-rate for all ages rises with increased density of population, but the rise is four times greater for infants than for other ages

The proper manner of feeding the baby after it has been weaned

A study of 844 breasted infants in Westminster (London) showed 84.8 per cent of them healthy, and that only 2.3 per cent died within one year. Of 140 bottle-fed babies 47.1 per cent were healthy and 12.1 per cent died in one year.

Though the right beginning for a baby is to be fed by its mother, there comes inevitably the time when the mother's milk no longer satisfies the baby, and it must have something more. It requires to be weaned, and very often indeed it suffers in the process, mostly because of the things we use to help it. No baby that has not completed its first year should be asked to digest any kind of starch. The baby does not have in its body the kind of digestive ferments which can digest starch, and therefore no food which contains starch is proper for an infant that is just being weaned. There is no starch in milk, but unfortunately mothers cannot be persuaded that milk is "solid nourishment," though the modern vogue of dry milk must have taught many.

The overwhelming value of milk as a food for children

The chief defect in the feeding of most children from weaning until they are far past their second year is that they do not get enough milk. Milk should remain the staple diet of a child for long after it is weaned. We should remember that many savage mothers do not wean their children until they are at least two years old, and that was probably the least period for maternal nursing in our species long ages ago. The one great staple food for childhood is milk, first, last, and all the time. And its own products, such as butter and cream, are its great allies.

Though milk contains no starch it has a valuable sugar in it; and we need not be afraid of letting young children have almost as much sugar as they feel inclined for, especially if it be the natural sugar in fruit. Sugar is a splendid fuel, with which young children can keep warm their small and therefore easily cooled bodies. Our grandparents were quite wrong in supposing that a child's fondness for sweet things was a sign of original sin. But we must certainly not use sugar to help us when we are weaning a baby, by putting it on a "comforter" or "pacifier," and letting the baby whom we are weaning suck that. No baby should have a "comforter" at all. It is a constant source of infection, not fit to put into a baby's mouth.

The discomforting effects of the so-called "comforter"

The proper name for this abomination is *discomforter*. Sucking at it makes the baby's saliva begin to run, and this soon interferes with its digestion. Even when the discomforter is solid, the baby usually manages to suck in a certain quantity of air; and this, together with the gas produced within the baby owing to its indigestion, naturally causes discomfort, crying, and flatulence.

Recently, also, the dental surgeons have shown that sucking at a dummy teat distorts the shape of the child's mouth, making the palate grow forward, and so ruining the natural shape of the jaws. Many of the ugly mouths and projecting upper lips we see in children and grown-up people are due to the "comforter." Precious little comfort it leaves behind it when the baby's mouth is distorted for life.

A "comforter", like a pipe, establishes a habitual need for itself, so that its discontinuance involves annoyance and irrit-

ability, which its resumption relieves. But this proves nothing in favor of the original employment of either. Mothers specially tend to use the comforter when babies are teething, but it is not worth while. The discomforter justifies its new name, by causing most, if not all, of the troubles which are supposed to be due to the teething, and for which the discomforter is supposed to be useful. The baby that is getting no starch, and that is getting plenty of clean milk, will cut its teeth with little trouble, or none at all. The bad reputation of teething, a perfectly natural and normal process, is mainly due to the stupid way in which we have been content to mishandle babies, and especially their stomachs and their mouths.

The true and invariable cause of infant rickets

There is a great delusion to the effect that rickets is only a weakness of the bones, and that, so long as they are all right (or apparently all right), a child must be free from rickets. But, in fact, rickets is a constitutional disease, caused solely by unsuitable feeding, which shows itself in a host of ways, if we know how to look for them; and it has gone a very long way before it tells upon the external appearance of the bones. Many babies have straight limbs, perhaps with plenty of fat upon them, who are rickety nevertheless. In many cases there is an excess of fat, which cannot be properly burnt up by the disordered chemical economy of the child; and these cases often deceive all but the expert, who knows how to look for the crucial signs of malnutrition.

Only the expert need study these signs; for the rest of us, it is sufficient to know how their appearance may be prevented. An abundance of fresh milk, as we have seen, comes first, and then good bread, not too starchy, but made from a good flour with the germ of the wheat-grain in it. Unfortunately, when we praise milk and its derivatives and applications, many mothers are inclined to think of pap, bread-and-milk and so forth, with nothing that can possibly need chewing. Then they are sorry that their children's teeth are so poor. Of course they are poor if the child's growing body was never given to understand that teeth and chewing were to be expected of it. That is the great mistake which has been made for many years past in the feeding of young children, and then we find, of course, that nine out of ten of the nation's primary public school-children need the dentist badly, and at once.

A child's teeth are meant to be used. Their use helps the blood to flow freely in the blood-vessels of the jaws, and so to make them and the teeth they bear as strong and well formed as they should be. Very few people know how much this means for beauty in later life. Children must have good, firm rusks, or toast, or crust of bread. Every doctor who has studied the subject is enraged when he sees the crusts cut away from children's bread. The crusts are richer than the crumb in nourishment, and they are invaluable as providing exercise for the teeth and jaws Not only does this exercise help the teeth and jaws themselves, but it starts the digestion of the food in the proper way by getting plenty of saliva mixed with it before it is swallowed.

The regulation of children's health by food possible without medicine

Some of the modern wheat-foods are excellent for children, both in themselves and because they need chewing. If our children are to have good teeth, properly developed jaws, and healthy mouths, we must stop feeding them on pap. And though a young child's teeth are only temporary, the better they are treated the more likely are their successors to be what are still kindly described as the "permanent teeth".

We have already seen that constipation in the mother is a source of danger to the nursling. Constipation in the child itself is to be regarded most seriously. A tiny infant should be most scrupulously observed in this respect, in which nearly all infants and young children give trouble at some time or other. When weaning has been accomplished, and we are doing our best to provide the baby with a suitable diet, which very likely comprises a boiled or otherwise sterilized milk, we often find that it becomes consti-

pated. Cows' milk is a constipating thing, especially if it has been boiled. The fat or cream in it is the constituent which helps to keep the bowels active, and hence cream and butter have a special value for young children beyond that involved in their high proportion of nutrient material.

The child must not be allowed to be constipated. The next thing will be that it is poisoned, and the opposite of constipation will follow, in the attempt of nature to get rid of the poisons which the constipation produced. But when a child is constipated we follow our usual rule with adults as with children, and begin to think of drugs first. That is where we are wrong. We should think of drugs last; and if we have done any good thinking before that we shall seldom reach them at all.

The high value of fruit as an element in diet

It is the diet that was wrong, and the diet must be attended to. A little more cream, for instance, may make all the difference.

Elsewhere in this section we have seen how valuable a part fruit may play in the dietary of the adult. But fruit is even more important for children. We all know how useful "fruit salts" may be, but do we all know how useful the salts in fruit may be? We still fancy that fruit is a luxury for children, presumably, because it is rather expensive, and because they are so fond of it. But fruit is a necessity in some form or other.

Orange-juice, lemon-juice, grapes, apples, prunes, figs, are all splendid things for children of all ages, to say nothing of grown-up people. Especially is this true of children who are being fed on boiled, sterilized, preserved, condensed or dry milk. Often a teaspoonful of orange-juice twice or three times a day has saved the life of a tiny infant, which was dying on some preserved artificial diet, just as Arctic explorers used to die of scurvy before the use of lime-juice made the discovery of both poles possible. The pathologists have not explained how it is that lime, lemon or orange-juice will cure or avert scurvy, whether in the adult or in "infantile scurvy", but the fact is unquestionable.

The unvitiated appetite of children a trustworthy guide

People who have made the experiment know that children who are allowed fruit, and even cake and sweets, freely do not exceed and make themselves ill The trouble is that, thinking ourselves so clever, we usually deprive children of these things, and then, of course, they take too much when they do get the chance, and make themselves ill. We should trust children's appetites far more than we do. Then we should have to give them medicine very seldom indeed, and only as a last resort.

A healthy child of twelve needs nearly as much food as an adult and of as great a variety. Milk or cocoa and water are the proper drinks, not tea nor coffee. Plain food, without rich pastry or puddings, hot breads, etc., must be the dietary, and the amount required will depend on the weight of the child; for example a child of three, weighing thirty pounds will need 980 calories each day; one of five weighing 40 pounds, 1200; one of fifteen weighing 100 pounds, 2000.

As for meat, which many very young children dislike, or like very little of, they are right — that is to say, nature is right, and we are wrong. Which is, of course, not so surprising, when we come to think of it. On the other hand, beef-teas and meat preparations have their uses in many cases, and often help the appetite and the digestion of ailing or weakly children. They are to be looked upon not so much as foods in themselves as aids to the absorption and utilization of other foods.

Hints as to the sensible clothing of children

The feeding of infancy and childhood is of transcendent importance, but there are many other factors of health which we should consider. In matters of clothing, the "golden mean", which Aristotle commended more than two thousand years ago, is still often ignored. Some mothers believe in the "hardening" system, which has frequently justified its name by achieving the stiffness of death. They send out their children inadequately clothed, forgetting

how small a child's body is, how easily cooled, and how ready, in that condition, to harbor the microbes of bronchitis and pneumonia. Fashion and appearances play a ridiculous part in this connection. On one and the same cold morning in December you may see children in almost any public park of whom one is quite bare-kneed, and wears nothing but thin socks, while another has warm stockings, plus gaiters, which cover the entire leg and knee. Both extremes can scarcely be right.

It is well known that the knee-joint, the largest and most complicated in the body, is specially liable to the attacks of the tubercle bacillus The physiologist — who knows how exposed the joint is, how incapable of producing heat on its own account, and how dependent upon an ample blood supply for the purpose of keeping up its temperature — cannot believe that the exposure of young children's knees to the cold winds of winter is a safe or rational proceeding. In general, it is a sound rule *not to chill children*, or any parts of their bodies.

The need for the open air in defiance of the weather

But it is no less sound a rule not to coddle them; and undoubtedly the "hardening school" stands for a very necessary protest against the view that children must be choked with woolen comforters and chest-protectors, and kept indoors whenever it is raining The inevitable result of these procedures is to lower, instead of educating, the child's powers of resistance; and some day, when it is exposed to no particular degree of vital strain, it will succumb. Children should not be chilled, but neither should they be coddled.

The best rule is to provide them with abundance of clean, warm, absorbent, *loose* clothing, and then let them take the weather as it comes. For it is vitally important that children should get exercise, which they need far more than *temperately living* adults do; and the exercise which is not conducted in the open air is little better than a farce. All the distinctions between open air and mere fresh but confined air, to which attention was drawn in an early chapter of this section, are valid, even more for children than for adults Man is not a mole, but an open-air animal, his young require exercise in the open air, of which all imitations are to be refused.

The open air as a preventive against adenoids

The properly clad child, with stout and entire soles to its boots or shoes, with hands and feet warm, and accustomed to play about in the open air in practically all weathers whatsoever, is the child least likely to catch cold, or any of the various forms of lung-infection. Not being subject to colds in early life, partly because it does not spend most of its time in a dust-laden atmosphere, this is the child that is least likely, so far as we know, to develop adenoids. It will be a nose-breather, and nose-breathers need concern themselves very little about the weather, for they carry their protective filter and air-warmer with them wherever they go. Already, in this section, reference has been made to the importance of nose-breathing, and the grave consequences of its chief obstacle, which is the presence of adenoids of the so-called "central" variety. The so-called "lateral" adenoids do not interfere with breathing directly, but they prejudice the hearing, and greatly increase the risk of infection reaching the middle ear from the throat, and perhaps doing irreparable harm to the drum.

The grave effects of adenoids, and some of their causes

An English authority on the subject, Dr. Macleod Yearsley argues that artificial feeding in infancy is a great cause of adenoids, because it involves unsuitable breathing on the part of the infant, unless very great care is taken; and it is indeed the fact that a great majority of adenoid cases occurs among the artificially fed, and a minimum in countries where normal maternal feeding is common. His conclusion is as follows: "Hence, in badly conducted artificial feeding, and in the use (or rather abuse, for it has no use) of the pernicious and abominable 'comforter', there is a fruitful factor in the occurrence of adenoids."

The need of guarding in infancy against future deafness

As a devoted student and champion of the deaf child, Dr. Yearsley should be listened to when he describes the early and neglected origin of the great number of those cases of deafness upon which quacks everywhere thrive. Here is what he says; and the parent who is not deaf to the voice of knowledge may save a child from a great disaster in years to come by listening now.

"It cannot be too vigorously stated, or too constantly reiterated, that chronic deafness in the prime of adult life depends, in the vast majority of cases, upon slow and progressive alterations, long unsuspected, because so insidious, in the middle ear. The fact that much of our normal auditory acuity is not required in everyday urban life makes this slow progress the more dangerous, for, so long as a conversation can be followed, or amusements enjoyed, the trouble passes unchallenged, and it is often not until hearing in one ear is nearly gone, and that of the other begins to go, that the patient awakens to his defect. It is in the course of the first years of life that the auditory apparatus is most exposed to inflammatory changes, and it is then that the foundations of chronic catarrhal deafness are laid down in the delicate middle ear, to develop insidiously and to overtake the victim somewhere about the full activity of the period comprised between the twenty-fifth and thirty-fifth years."

Deformities that come to children through undue strain

The limbs of a young child are possessed of what is, in large measure, a merely cartilaginous or gristly skeleton. They must not be exposed to too much strain. We constantly see small children who are allowed to go about on legs which are visibly buckling under the strain. This happens not least with heavy children, where the superfluity of fat and the special weakness of the bones are both due to the familiar cause, rickets. Of course, it is a great cruelty and injustice to a child to bend its limbs in this fashion, even though surgery might later straighten them. The simple ways of ensuring that a child grows up neither bow-legged nor knock-kneed are two. First, no young child should be allowed to remain on its legs too long at a time; the proper and natural exercise for childhood is rapid alternation of "spurts" and rest. Second, by attending to the diet of the child we can prevent that constitutional state of malnutrition which makes the young bones easy victims of undue pressure from above

Not much less familiar is the deformity of the spinal column due to strain and neglect, and, in some cases, to unsuitable positions when reading and writing. These conditions are a source of income to doctors and masseurs and physical culture experts, for they are extremely intractable, and very likely to recur once they have established themselves, but they are easily preventable by parents who prefer to follow the almost costless and wholly common-sense injunctions of the present chapter. The child that is expected to use its limbs as it will, to hop and skip and jump in loose, warm clothing, in every kind of weather, and that is not expected to use its naturally long sighted eyes at short range with lesson-books for several hours a day, will not suffer from curvature either of the spinal column or of the two columns upon which it is supported.

One of the recognized topics for discussion in regard to the hygiene of childhood is ventilation. Of course, a child's nursery and schoolroom should be airy and well ventilated. Of course, the bedroom window should be open at night. Certainly there should be as little dust as possible, and therefore as little as need be of the kind of hangings and floor-coverings from which dust is largely derived.

But our discussion on the subject would be out of touch with modern knowledge if we said anything to suggest that even the very best rooms are the right environment for a child that might be getting out into the open air. That point has been established for adults; and the experience of open-air schools, beginning with the famous Forest School at Charlottenburg has established it still more amply for children.

IN THE PATH OF A WHIRLING CYCLONE

Courtesy Weather Bureau, U S. Department of Agriculture

AN APPROACHING CYCLONE

These two photographs were taken in immediate succession, the upper first, at Elmwood, Nebraska, on April 6, 1919, by B. G. Pickwell, who was very near the path of the tornado.

ATMOSPHERIC MOVEMENTS

How the Heat and Flow of the Air are Measured and Weather Wisdom Sought

GALES FROM THE WHIRLING EARTH

WE may ignore the weight of the air, or its humidity, or its radioactivity, but its temperature forces itself upon our notice. A temperature of 125° F. in the shade, or −40° F., refuses to be ignored. Nor is the temperature of the air important merely in its relation to our skin and our circulation; it has such far-reaching consequences as tempests and typhoons, as trade winds and anti-trade winds. Heat it was that took Christopher Columbus to America, just as certainly as it is heat that today takes our great liners across the Atlantic.

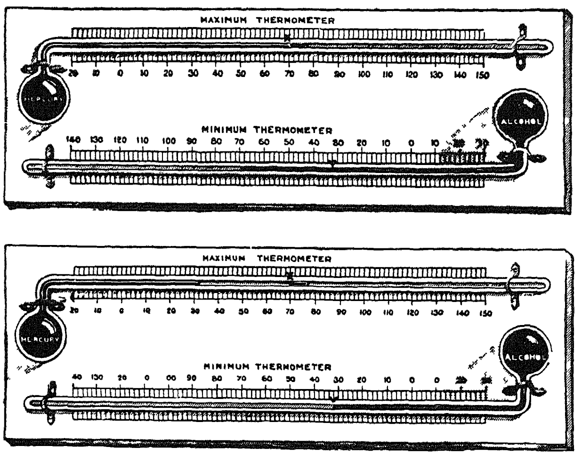
Before, however, we discuss the far-reaching consequences of the heating and cooling of the air, it will be well to look at the thermal facts themselves. In the first place, how is the intensity of heat measured? Usually by means of instruments known as thermometers, which are constructed on principles we shall now briefly describe.

The ordinary thermometer consists of a little bulb ending in a narrow closed tube. There is enough mercury in the instrument to fill the bulb and extend some way up the closed tube. The tube above the limit of the mercury is emptied of air, so that it is practically a vacuum When heat is applied to this bulb and tube of mercury, the mercury expands, and the upper limit of the mercury in the tube rises, and rises in proportion to the heat applied. By grading the tube accordingly, and marking the point to which the expanding mercury rises, we can measure the temperature. Instead of mercury some other expansile liquid such as alcohol may be used.

Two thermometers, differing in their graduation, known respectively as Fahrenheit and centigrade, are in common use today. The former, named from its inventor, divides the extent of expansion between the freezing and boiling points of water into 180 degrees, and, marking the freezing-point 32, marks the boiling-point, accordingly, 212 Its zero is thus 32 degrees below the freezing-point of water. The centigrade thermometer, on the other hand, divides the expansion between the freezing and the boiling points of water into 100 degrees, and, marking the freezing-point zero, marks the boiling-point 100 degrees A hundred degrees on the centigrade scale thus equal a hundred and eighty degrees on the Fahrenheit. On both thermometers the degrees are marked up beyond the boiling-point, and down below the freezing-point. Mercury freezes at −40° F., *i e* 72 degrees below the freezing-point of water, and therefore for recording very low temperatures an alcohol thermometer is better than a mercury. In the Réaumur thermometer, little used, the freezing-point of water is marked zero and the boiling-point 80°.

Thermometers are graduated by first plunging them into melted ice, and marking the point to which the mercury or other liquid contracts, and then putting them in the vapor of boiling water, and marking again the point to which the mercury or other liquid expands Allowance must be made for variation in the boiling-point due to varying atmospheric pressure. The length so marked is then divided into 80, 100, or 180 degrees, according to the scale to be used.

Thermometers are also made which continuously register the temperature by means of a pen tracing on a moving drum. In one type of these so-called thermographs an expansile liquid fills a curved, closed tube, and as the liquid expands it straightens the tube in its effort to make more room. One end of the closed tube is fixed, but the other end is free, and to this free end is attached the registering pen to record its movements; and its movements recording the expansile movements of the tube necessarily record the intensity of the heat to which the liquid has been exposed. Thermographs based on the change in shape of a curved strip composed of two metals having different coefficients of expansion, are more common in this country.



THERMOMETERS THAT RECORD HEAT AND COLD

These pictures show the working of maximum and minimum thermometers, the indicators, x and v, marking the highest and lowest temperatures reached In the lower picture the minimum thermometer is at 32°, the lowest point reached overnight The alcohol carried the indicator, v, to this point, and left it there when the temperature rose, as in the upper picture In the maximum thermometer of the upper picture, the mercury is at the supposed highest temperature of a day It has pushed the indicator, x, to 70°, and when it shrinks to a lower temperature, as in the lower picture, the indicator is left at 70

In order correctly to determine the temperature of the air, the thermometer must be screened from the direct rays of the sun, since the sun would heat the thermometer much more than it heats the air. The sun's rays, indeed, pass through the air and heat it comparatively little, and the heat of the air is due more to the radiation of heat from the earth than to the direct rays of the sun. As we ascend above the earth up to about seven miles, the temperature of the air steadily falls. Thus a free balloon carrying a self-registering thermometer which was sent up from Trappes, in France, when the surface temperature was 50° F., registered a temperature of −58° F. at a height of six miles; one from Strassburg, at a temperature of 43.3° F., registered −65° F. at about the same height.

Apart from height, the temperature of the air is in proportion to the direct heat of the sun; and this, as we have already explained, varies with the obliquity of the sun's rays. But the temperature of the air also depends on the nature of the surface on which the sun-rays fall. Thus land is more quickly heated by the sun than water, and radiates heat to the air more quickly. Water, on the other hand, stores more heat than land, and radiates heat to air when the land is quite cold. It is for this reason that the sea modifies both the heat and the cold of the land, and that inland places have greater extremes of temperature than places by the sea. The sandy soils of deserts may be heated almost to 200° F. by the sun, and when the hot sand is raised by simooms the temperature of the air may rise to 125° F., or even more.

Such disturbing factors as these, especially the irregular distribution of land and water, render the distribution of heat rather irregular, and only in a rough and general way can we assert that the nearer the equator the greater the heat

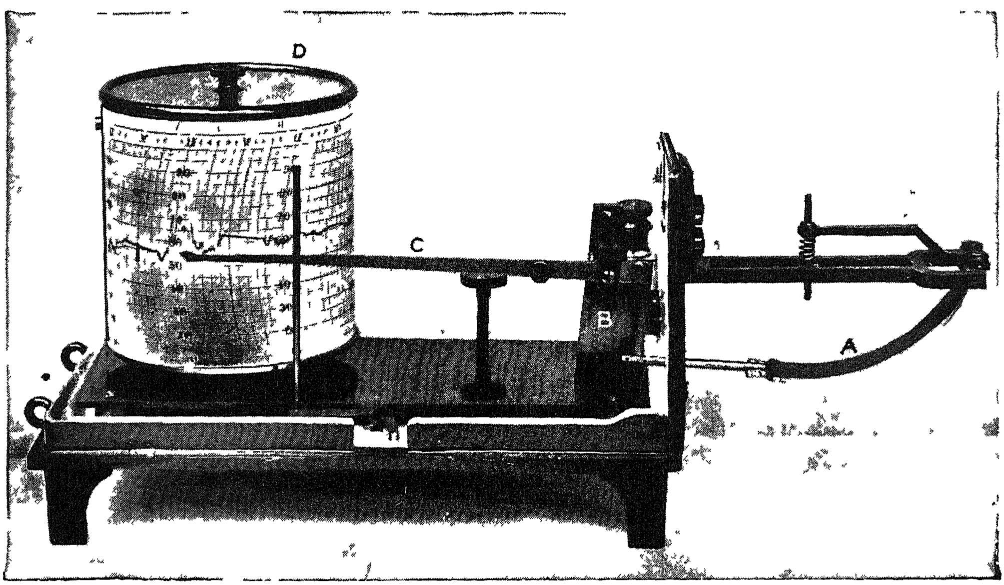
Meteorologists have constructed very interesting maps with lines known as "isothermal lines" running through places with the same mean annual temperature, and these lines are found to have wavy, undulating courses, and not to run parallel to the equator. The median line of the zone of greatest mean heat is found to run not through the equator, but slightly north of it, and its margins are wavy, with tongues running northward into India, and southward into Africa and South America. In January the Shetland Islands are on an isotherm that runs through our Southern States, in July on one through Alaska.

The atmosphere, then, is heated in this irregular manner by the sun, and the result is wind. Were it not for the unequal heating of the atmosphere, it would be stagnant as a mill-pond; but the sun heats and expands it and fills it with water-vapor, and gives it tides and currents like a sea.

The great currents of the atmosphere are the "trades" and the "anti-trades", and they are simply hot and cold currents of air running between the poles and the equator, and deflected by the motion they receive from the whirling earth. Let us look into the physics of these great heat-currents.

The hottest air is that in the belt we have already mentioned which runs round the earth a little north of the equator, and this belt is the mainspring of the great atmospheric current. The air of this belt being heated and laden with moisture, expands and rises, and is heaped up above the general surface of the atmosphere. Naturally it does not remain heaped up, but flows away towards the poles, while the heavier, colder, denser air from the poles rushes along the surface of the earth toward the equator in an effort to restore equilibrium. It is much the same as happens when a window is opened top and bottom in a room with heated air The heated air pours out at the top and the cold, denser air rushes in at the bottom to restore the balance. The heated expanded air, indeed, may be regarded as a partial vacuum.

The heated upper air floating north and south from the heated zone constitutes the anti-trade winds, while the cold currents flowing from the poles are the trade winds. The trade winds run north and south from the poles, and the anti-trade winds north and south from the equator, but in no case is the direction due north or due south. How is this?

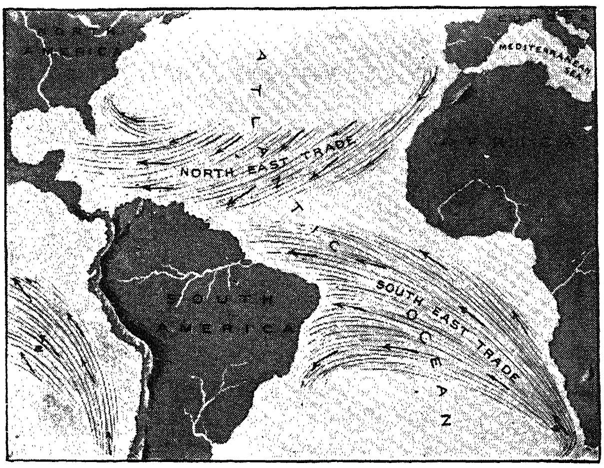


THE THERMOGRAPH, THAT RECORDS THE VARIATIONS OF TEMPERATURE

The curved tube, *A*, is filled with liquid which, as it expands and contracts, moves the marker, *C*, up and down, by means of the levers at *B* On the drum, *D*, revolved by clockwork, is a chart on which a week's record of the variation of temperature has been marked.

Let us consider the relation of the atmosphere to the earth's rotation. The atmosphere is bound to the earth by gravitation, and, apart from disturbing factors, earth and atmosphere turn together as if a continuous whole. The atmosphere above the equator whirls round with the equatorial belt, which, as is well known, is larger than the polar belt. The atmosphere, likewise, in the Arctic Circle whirls round with its smaller circle of latitude, completing a much smaller circuit in twenty-four hours, and therefore moving much more slowly than the air above the equator.

In general, therefore, it is plain that the atmosphere moves more and more slowly in its eastward rotation with the earth the farther we recede from the equator, and the nearer we approach the poles. Now, hot air rising from the equator and flowing towards the North Pole retains as it flows the rapid eastward motion it had when it started; and this motion as it reaches northern latitudes is quicker than the motion of the surface of the earth in these latitudes. Accordingly, the air flowing northward deviates eastward across the more slowly eastward-turning surface of the earth. That is to say, it seems to come from the southwest and to be a southwest wind. Hence the "anti-trade" flowing in the upper atmosphere northward from the equator is a southwest wind. The "anti-trade", again, flowing southward from the equator, becomes on the same principle a northwest wind.



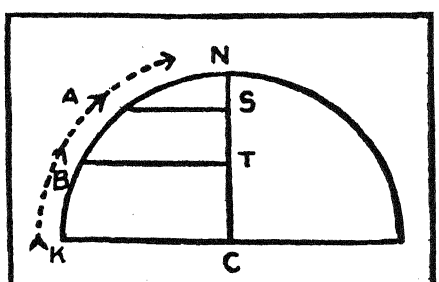
THE DIRECTIONS OF THE ATLANTIC TRADE WINDS

Let us see next in what direction the trade winds deviate, and why. The north trade wind starts from the northern portions of the globe, and flows in the lower layers of the atmosphere towards the equator. It starts with a very slow eastward drift, since in the northern latitudes the atmosphere is carried only slowly eastward, and the result is that, as it flows southward, the more quickly rotating lower latitudes outstrip and pass it. The result is a wind that seems to come from the northeast. This is not quite easy to understand at first, and an illustration will make it plainer. Suppose a steamer proceeding east at twenty miles an hour, and a west, or fair, wind blowing eastward at ten miles an hour, in what direction will the wind seem to be to people on the deck of the steamer?

Obviously, though the wind is really west, the quicker motion of the steamer creates an east wind, and the passengers will be mislead into thinking that is the wind's direction. In just the same way, though the trade wind is coming from the west and going eastward, the earth is rotating eastward faster still, and so outstrips the west wind, and creates an east wind of its own. In like manner the trade winds blowing from the South Pole appear as southeast winds.

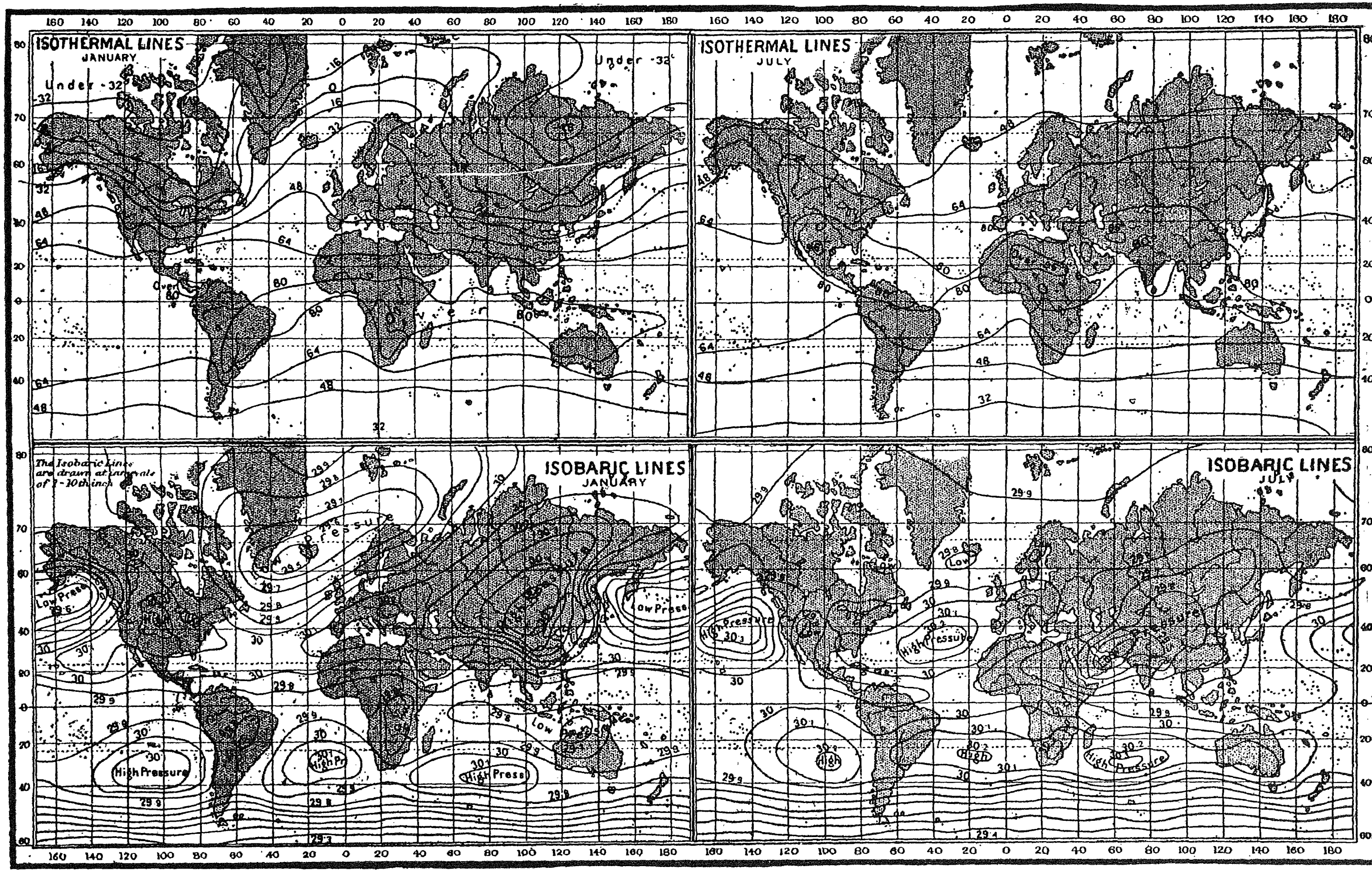
We have said that the trade and anti-trade winds retain the velocity imparted to them at their start by the velocity of the earth. If we toss up a ball in a moving railway train, the ball retains the forward momentum imparted to it by the train, and falls on the floor of the car, even though the floor be moving at sixty miles an hour. And on the same principle the wind retains its initial velocity.

But in the case of the trades and anti-trades, an additional law comes into play. As the trade winds proceed northward they approach nearer and nearer the axis of rotation of the earth. NC being the axis of rotation of the earth, and KBA being



the trade wind at various stages of its northward journey, it is plain that BT is less than KC, and AS less than BT.

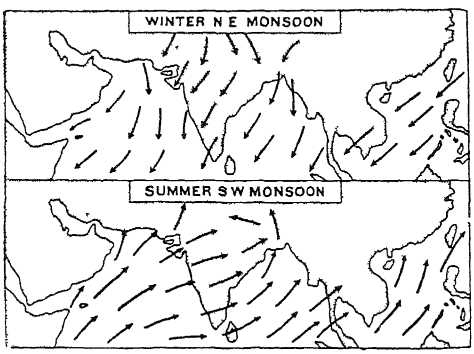
PLACES WITH SIMILAR HEAT & AIR-PRESSURE ROUND THE WORLD & THROUGH THE YEAR



ISOTHERMAL LINES SHOWING HEAT OF EQUAL INTENSITY ALONG THE COURSE OF EACH LINE, AND ISOBARIC LINES GIVING BAROMETRICAL PRESSURES

This approach of the wind nearer to the center of rotation quickens its speed. To illustrate: if we tie a weight to a stick by a string, and whirl the weight round so that the string winds up, the weight circles the stick more quickly as the string shortens. Thus the trade wind not only retains its initial velocity, but acquires more speed eastward as it proceeds northward. By the same law, the anti-trades coming from the poles towards the equator, and receding from the axis of rotation as they proceed, must slow down.

At the surface of the earth the northeast trades are found to prevail from about 29° north to 7° north latitude, and the southeast trades from about 3° to 20° south latitude. Between these trade winds there is a belt of calms varying in width from 150 to 500 miles; the average position of the middle of this belt, called by sailors the "doldrums", is in latitude 5° north. On the outer margin of the trades there are two other regions of calm, called the "horse latitudes", and beyond these we find again in the northern hemisphere prevailing southwest winds and in the southern hemisphere prevailing northwest winds. The calms of the horse latitudes are due to the cooling of the anti-trades which descend and interfere with the trades.



THE MONSOONS OF SOUTHERN ASIA

Though a great part of the anti-trade wind cools and descends, there is always an upper layer which proceeds towards the poles, and on the tops of all high peaks we can always find eastward anti-trades, even when northeast or southeast trades are blowing below; and volcanic dust and clouds when high in the air go eastward.

After the trades and the anti-trades, which are constant or regular winds, come the seasonal or periodic winds such as the Indian monsoons which are produced as follows. The land becomes so heated during the summer time that the air over it becomes hotter than the equatorial air, and accordingly hot air is drawn from the equator to India. Again, since the air drawn from the equator retains its great equatorial eastward velocity, the wind seems to come from the southwest; hence we have in summer the southwest monsoon. In winter the current is reversed, and there is a northeast monsoon blowing from the land.

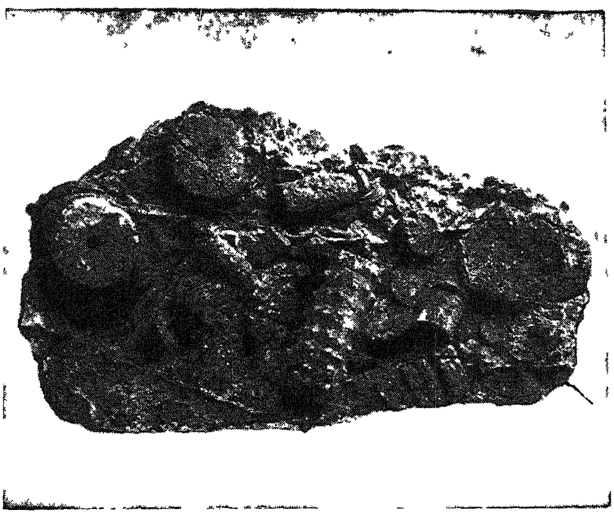
It may be a little difficult at first to understand the behavior of these great winds, but the general principles of their movement is clear: they are the results of the irregular heating of the earth's surface by the sun, and the deviation in direction, owing to the rotation of the earth, is of secondary importance.

Not only the great winds but the small winds are due to inequalities in heat. In the daytime on the sea-coast there is a breeze from the sea, since the land is hotter than the sea, and heats and expands the air over it, but after the sun sets, and the heat has radiated from the land, the sea is hotter than the land, and a breeze therefore blows from the land to the sea Again, at high altitudes during the day, when the high land is heated by the sun and rendered hotter than the plains, a breeze blows uphill from the cooler valley land, but at night, since the high land grows cool more quickly than the low land, the direction of the wind is reversed. The *mistral* of the Riviera is a cold northwesterly wind which rolls down on the plains from the cold summits of the Cevennes and the Maritime Alps.

But, besides the great trade and anti-trade tides, and the fluctuations due to such known alternations of heat and cold as we have mentioned, the ocean of air, like the ocean of water, is full of traveling whirls and eddies of various sizes, and it is these that constitute the ordinary winds and gales, and to a great extent determine the weather.

Any considerable alteration whatever in local air-pressure, whether the alteration be due to heat or water-vapor, or both, is followed by wind. If the pressure be lowered, air flows in all round to equalize the pressure; if the pressure be increased, air flows outwards to restore equilibrium. The inward flow of the air toward a center of low pressure is called a "cyclone", or cyclonic movement, and the outward flow of the air from a center of high pressure is called an "anti-cyclone", or anti-cyclonic movement.

In both cases, however, the air does not flow straight in or straight out, but proceeds in a spiral course. The spiral motion is caused by the earth's motion, and varies in direction. In the northern hemisphere the spiral whirl of a cyclone flows inwards in a spiral which turns in the opposite direction to the hands of a watch; while the spiral whirl of an anti-cyclone turns in the other direction. In the southern hemisphere, on the other hand, cyclones and anti-cyclones whirl in just the reverse directions, the southern cyclone turning in the direction of the hands of a watch.



HOW WIND AND RAIN WEAR AWAY ROCK

In this fragment the softer limestone has been worn away, leaving the harder fossils imbedded in it to stand out in relief

The following practical rule, known as Professor Buys Ballot's law, gives the direction between wind and pressure for the northern hemisphere: "Stand with your back to the wind, and the barometer will be lower on your left hand than on your right; hence it follows that if you stand with the high barometer on your right and the low barometer on your left, the wind will blow on your back. In the southern hemisphere the rule must be reversed, 'right' put for 'left' and 'left' for 'right'."

An anti-cyclone, commonly called a "high", is usually a very stationary eddy, and the air descending in its spiral is free from moisture; it is thus usually associated with good weather. In summer anti-cyclonic weather is calm, cloudless and sunny; and in winter, calm, cloudless and frosty.

A cyclone is not a stationary eddy; it is always moving, and sometimes moves at a great rate. It usually brings rain and cloudy weather, since the vapor in the rising air condenses as it rises.

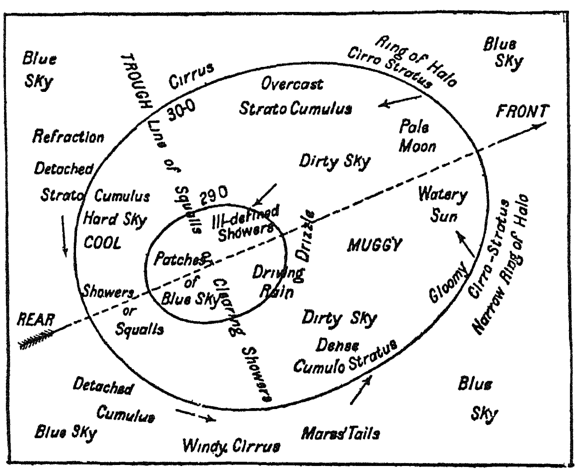
Since fall of pressure is usually associated with bad weather, and rise of pressure with good, barometers evidently may be used to foretell the weather. But in most cases the important thing is not the mere rise and fall, but the rise and fall relatively to surrounding areas, and this can be found out only by a comparison of local readings; and nowadays such comparison is made by charting on a map a collection of readings telegraphed by various meteorological stations. In this way we can draw curved lines of equal pressure, which are called "isobars", and the charts so drawn will show cyclones or anti-cyclones as in the diagrams. The Weather Bureau publishes every day a map of this kind for the United States and from it the weather forecast is made.

Isobars are usually drawn to indicate successive differences of pressure equal to that of one-tenth of an inch of mercury. The closeness of such isobars is evidently an indication of the gradient of the fall which is stated as so many hundredths of an inch of barometric pressure in a distance of 60 nautical miles (one degree).

Thus, if two barometers 60 miles apart differ by $\frac{3}{100}$ of an inch, the gradient is said to be 3. The deeper the depression and steeper the gradient, the stronger the wind.

Thus, from a weather chart we are able to foretell weather to some extent. If we know that the central depression of a cyclone is advancing in a certain direction, at a certain rate, we can tell approximately its future course, and the date of its arrival at various districts.

When a cyclone has a very deep and steep central depression, and whirls and advances with great rapidity, it becomes what is known variously as a typhoon, hurricane, whirlwind, simoom or tornado. Such violent whirls are always caused by the rapid local heating of the lower layers of air, so that a column of hot air rushes up like that which belches from a furnace chimney. Miniature tornadoes are often seen whirling about on hot deserts, or even on hot roads, raising little fountains of dust as they whirl.



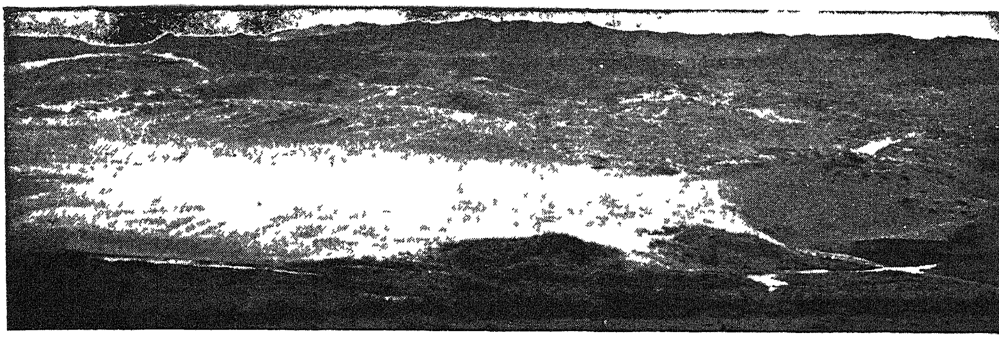
THE WEATHER OF A TYPICAL CYCLONE
(After Abercromby and Marriott — from the *Quarterly Journal of the Meteorological Society*)

In Europe, North America, the West Indies, the China Sea, the Bay of Bengal, on the east coast of Africa and in the Sahara, violent and destructive cyclones are far from uncommon. The late Professor N. S. Shaler thus described a destructive North American cyclone:

"In its path over the surface, the circling movement of the writhing air, and the sucking action of the partial vacuum in the center portion of the shaft, combine to bring about an extreme devastation. On the outside the whirl of air, which rushes in a circling path towards the vortex, overturns all movable objects; and in the center these objects, if they are not too heavy, are sucked up as by a great air-pump. Thus the roofs of houses, bodies of men and animals, may be lifted to great elevations, until they are tossed by the tumultuous movements beyond the limits of the ascending current, and fall back upon the earth. When the center of the whirlwind passes over a building, the sudden decrease in the pressure of the outer air often causes the atmosphere which is contained within the walls suddenly to press against the sides of the structure, so that these sides are driven quickly outwards as by a charge of gunpowder."

The following account of a tornado in Minnesota is taken from Ferrel.

"The tornado struck the Mississippi River at a point opposite to the village of Sauk Rapids, and fishermen who were in full view of the crossing aver that for a few moments the bed of the river was swept dry; and in corroboration of this remarkable statement they showed me a marshy spot where no water had been before this event took place. Two spans were torn away from the substantial wagon-bridge below the rapids, one span being hurled up-stream and the other down it by the rotatory motion of the blast, great blocks of granite being also torn bodily out from the piers. The large flour-mill near the bridge was leveled. The depot of the Northern Pacific Railway was demolished, and the central portion of the village itself was attacked with the greatest violence. Being the county seat, the courthouse was located here, a substantial structure, of which only the vault, six iron safes and the calaboose were left — the latter turned upside down. A fine new schoolhouse, costing $15,000, was completely swept away. The Episcopal church was so utterly ruined that the sole relic thus far found is a



SAND DUNES INVADING THE LAND AND FORCING BACK CULTIVATION ALONG THE COAST

battered Communion plate. The floor of the skating-rink is all that is left of that structure. Stores, hotels, a brewery, and four-fifths of the residences in the village were scattered as rubbish along the hillsides, or borne away for miles through the air."

Another sensational example occurred in Illinois on June 4, 1877, where a man saw a tornado strike his house, and "the house appeared to go up bodily and plunge into the cloud. Only a very small portion of it was ever seen afterwards."

The average rate of surface wind on land is from six to twelve miles an hour. On sea and at high altitudes the velocity of the wind is greater; and in winter the cirrus cloud, which is one of the upper clouds, travels over ninety miles an hour. Tornadoes sometimes go hundreds of miles an hour. Winds are named breezes, gales, etc., according to their rate; and the following table gives the relation between their names and velocities:

Description of Wind	Velocity
Calm	3 miles per hour
Light air	8 " " "
Light breeze	13 " " "
Gentle breeze	18 " " "
Moderate breeze	23 " " "
Fresh breeze	28 " " "
Strong breeze	34 " " "
Moderate gale	40 " " "
Fresh gale	48 " " "
Strong gale	56 " " "
Whole gale	67 " " "
Storm	75 " " "
Hurricane	90 " " "

The winds of the world are the daughters of the sun, and are full of the sun's energy; and a good deal of the energy of the sea, its waves and its currents, are due to the action of the wind.

SAND DUNES THAT ACT AS A DEFENSE AGAINST THE SEA, AND ALSO SHIELD CULTIVATED LAND

Every puff of wind means a wave; it pushes the water before it into a heap, and this swings up and down and is repeated across the sea. Strong winds make huge waves, but waves are never mountains high; the highest measured were only 50 feet from trough to crest, with about 400 yards between successive crests. But the wind does more than produce waves; it also produces what is called "surface drift" — *i.e.* it drives the top layer of water before it and, in fact, skims the surface of the sea as one skims the cream off milk. In this way currents are set up in various parts of the ocean which, more or less, agree in direction with the direction of the prevailing wind. Pieces of wood and nuts and seeds are sometimes carried right across the Atlantic by surface drift, and, as is well known, Columbus received his first intimation of the nearness of land through objects drifting in the Atlantic. The best-known surface drift current is the Gulf Stream but, as we shall see when we come to deal with the ocean, there are many smaller currents all over the world.

When the wind blows off the land the sea near shore is colder, as bathers know, than when it blows landward. The reason of this is that a seaward wind blows the warm surface layers seaward, off the top of the sea, while a landward wind drives the warm surface layers landward.

The wasting power of wind-blown sand over rocks

When we come to speak of climate, we shall see that the direction of the prevailing wind is a very important factor in climate. All meteorological stations possess instruments called anemometers, which register automatically the force and the direction of winds.

The wind troubles not only the sea — it also gnaws away at the land. Even as it carries along the salt spray of the sea, so does it carry along the sand of the seashore. On a windy day the wind along the shore is full of sand, and this sand is nature's file and sandpaper, wherewith she polishes and glazes the rocks and crags of the sea-coast. But not only does the sandpaper polish — it also wears away.

Window-glass along the shore at Cape Cod, for example, loses its transparency in a day or two and is sometimes cut through in a month by the storm-driven sand. Telegraph poles in Southern California have been cut down by nature's sand blast and hard rocks in many places carry the autograph of the prevailing sand-laden winds.

By the accumulation of sand, again, hillocks of sand, or "dunes", are formed. Around the Gulf of Gascony, in France, there is a long, ridged dune almost 300 feet high at its highest point; and the dunes of Cape Bojador, on the northwest coast of Africa, and of Cape Verde Island, attain a height of from 390 to almost 600 feet. The usual habitat of dunes are the sandy shores of seas and large lakes, sandy valleys and broad sandy plains. So we have dunes at many points on the Atlantic Coast and along the shores of Lake Michigan.

But sand does not always end in dunes; sometimes it invades fertile country and overwhelms, as in Bermuda, gardens and fields and woods. On the west coast of Europe, from the Pyrenees to the Baltic, blown sand advances landward at the rate of three to twenty-four feet annually, overwhelming houses and fertile fields in its advance. On the shores of Lake Michigan, the sand has covered swamps and forests, and even low hills.

The entombed cities of antiquity and their concealed history

But not only along the sea-shore are the effects of sand carried by wind noticeable. The same things happen in the great deserts of the world, such as in the Sahara, the center of Asia, and the interior of Arabia. In Mesopotamia and Central Asia many ancient cities lie entombed in sand, carried by wind from the desert, such as the famous cities of Nineveh and Babylon, Ur and Erech, and innumerable towns have been buried on the west bank of the Nile between the Temple of Jupiter Ammon and Nubia It is likely that the chief discoveries of the future which will throw light on the disconnected history of the peoples of the East lie hidden at this moment under the sands from Mesopotamian and Arabian deserts.

Science and Progress (1815-95) II

by JUSTUS SCHIFFERES

LAWGIVERS OF ELECTRICAL SCIENCE

IT is difficult for us who live in this electrical age to realize that not so many years ago electricity was almost unknown and certainly not appreciated. In the Napoleonic era and for several decades thereafter, it was generally regarded as a pleasant diversion for "electricians" in their laboratories; but it was held to be of no concern to practical men.

The story is told that Michael Faraday, when he was director of London's Royal Institute, tried to explain the workings of a simple piece of electrical equipment to William Gladstone, then Chancellor of the Exchequer. The eminent statesman could not understand the functioning of the apparatus. "But after all," he cried in his chagrin, "what good is it?"

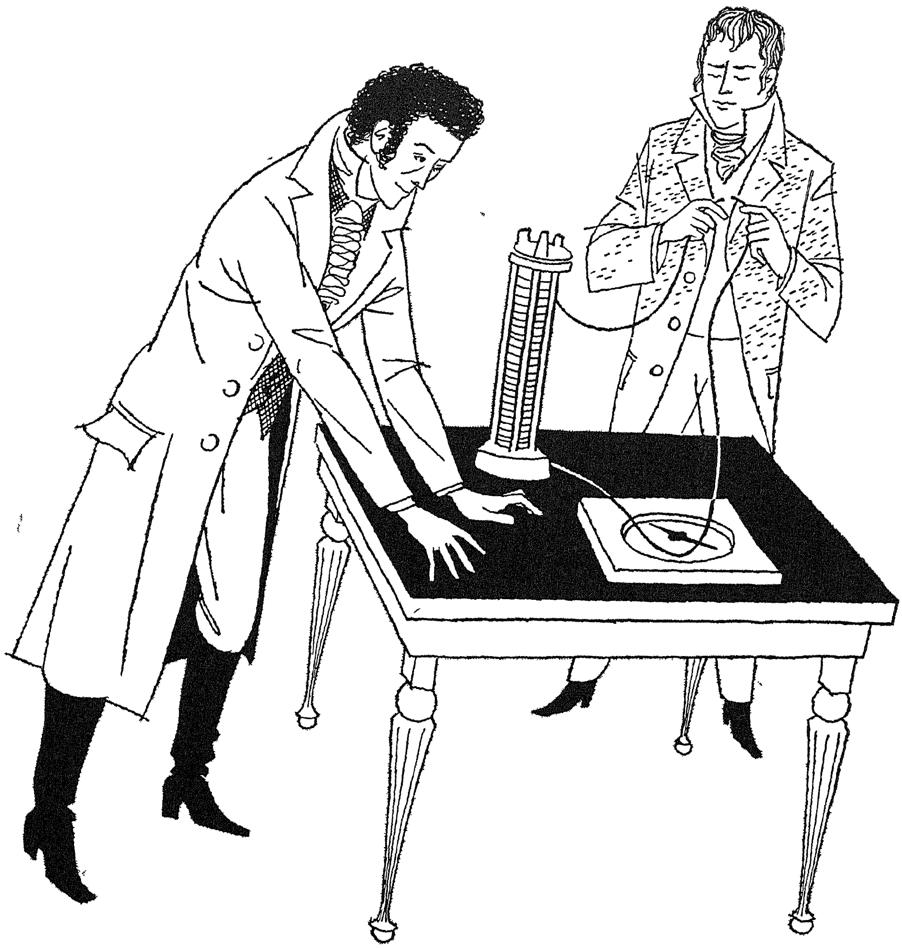
"Why, sir," replied Faraday, "presently you will be able to tax it." Every dynamo that runs today, every motor that turns bears witness to the truth of this prediction.

In an earlier chapter of this group, we gave some idea of the fumbling origins of electrical research. By the first years of the nineteenth century a certain amount of theoretical knowledge had been acquired, but the practical importance of electricity was just about nil. It was not until men came to appreciate the importance of electromagnetism and to apply it to the work (and convenience) of the world that electricity became an important factor in everyday life.

The man who opened this new era was the Danish physicist Hans Christian Oersted (1777–1851). The son of an apothecary, he was graduated from the University of Copenhagen with high honors. After five years of study in foreign countries at the expense of the state, he returned to his native land. In 1806 he was appointed professor of physics at the University of Copenhagen and he began the experiments that were to bring him fame.

As early as 1807 Oersted had described certain researches whose purpose was "to ascertain whether electricity . . . had any effect on the magnet." In a famous experiment in 1819 he showed that magnets are indeed affected by an electric current. He set a compass (which, of course, is a magnetized needle swinging freely on a pivot) upon his lecture-room desk. Over the compass he placed a copper wire through which an electric current was flowing. The needle moved! Furthermore, it was always deflected in a definite way, depending upon the position of the wire and the direction of the current. In 1821 Oersted published the results of his experiments, attested to by sundry Danish noblemen, in a formal Latin essay entitled Experiments on the Conflict of Electricity in Magnetic Pointing.

Most importantly, these experiments revealed for the first time that electricity is capable, like gravity, of "action at a distance." That is to say, electromagnetism can produce effects without direct contact. Oersted observed that these effects "are not changed if the magnetic needle is shut up in a copper box filled with water. It is unnecessary to state," he added, proudly, "that the action of these electric effects *through* such materials has never before been observed." Oersted received many honors for his contributions to electrical research. The Royal Society awarded him the Copley Medal; the Institute of France gave him a



Oersted was the first to show the relationship between magnetism and electricity. When he placed a copper wire, through which electricity was flowing, over a compass, the magnetized needle of the compass moved.

prize of 3,000 francs; his fiftieth anniversary at the University of Copenhagen — as student and professor — was publicly celebrated.

Oersted's work in electromagnetism greatly interested the French physicist Dominique-François-Jean Arago (1786–1853). "While I was repeating the experiment of the Danish physicist," wrote Arago in 1820, "I noticed that the same current produces a strong development of the magnetic condition in bars of iron and steel which before were entirely devoid of it . . . The connecting wire [a copper coil, or helix, into which the metals were thrust] communicates to soft iron . . . a temporary magnetization." Arago had constructed the first electromagnet ever devised by man.

Arago noted also that "if we use little pieces of steel, it gives them a permanent magnetization." For hundreds of years the only way to magnetize a steel bar permanently had been to rub it with lodestone (the iron ore now called magnetite). Later it had been demonstrated that a steel bar could be magnetized by another bar that had already been rubbed with lodestone. With the new electromagnet, the permanent magnetization of steel bars became an even simpler matter.

Arago lived an exciting life as a scientist and public official. He was born in Estagel, entered the Paris Polytechnic School in 1803, joined the staff of the Paris Observatory and was sent to Spain in 1806 to make certain astronomical observations. Caught in the Napoleonic War between France and Spain, he was captured and imprisoned, but escaped to Algiers.

After more adventures, he returned to France in 1809, still carrying the records of his astronomical observations. He was immediately elected to the French Academy. Later he became the permanent secretary of the academy. An ardent liberal in politics, he took part in the revolutions of 1830 and 1848. After the second of these revolutions he served as minister of war and marine in the provisional government. He opposed the election of Louis Napoleon as president of the Republic of France; the latter's triumph put an end to Arago's political career.

Ampère was a pioneer in electrical research

Arago's distinguished colleague at the Polytechnic School — André-Marie Ampère (1775–1836) — also did pioneer work in the new field of electromagnetism. The son of a merchant who died on the guillotine during the French Revolution, Ampère made his way by his mathematical skill. His first important teaching post, at Lyons, came as the result of a paper he published on the mathematical theory of probability. In 1809 he became professor of mathematics at the Polytechnic School, and he soon established a reputation as a prominent investigator of electrical phenomena.

Ampère demonstrated that electric currents act on magnets and also on each other according to perfectly definite mathematical formulas. Among other things, he established the principle called Ampère's Law, which states that under certain circumstances the magnetic effect of an element of a circuit varies inversely as the square of the distance. This distinguished investigator gave his name to the electrical unit known as the ampere (see page 380).

Another lawmaker of this fruitful period was the German physicist Georg Simon Ohm (1787–1854). While professor of mathematics at the Jesuits' College at Cologne, he did extensive research on voltaic batteries and galvanic currents. In 1827 he formulated and published what is known as Ohm's Law: "The intensity of the current in a circuit is equal to the electromotive force that drives it divided by the resistance that the current meets."

Resistance and the flow of electric current

Resistance is a very important factor in the flow of electric current. If there were no resistance to the passage of electricity, it could not be used to yield heat, as in toasters or in electric furnaces; nor could it yield light, as in electric bulbs. On the other hand, the resistance of wires to currents — a kind of internal friction — causes energy to be dissipated continuously. It was energy dissipation of this kind that made it almost impossible to get the first long undersea cable, connecting Europe and America, to work.

Ohm's findings were not generally accepted by his academic colleagues in Germany, including the members of the Berlin Academy Piqued, he resigned his teaching post at Cologne and went into retirement for a number of years. He later taught at the universities of Nuremberg and Munich and did distinguished research in the field of acoustics.

The greatest name in the history of electrical research in the first half of the nineteenth century is that of Michael Faraday. His career furnishes a classical example of a poor boy who made good as a scientist. Born in Newington, Surrey, in

1791, Faraday was the third son of a poor blacksmith, who later came to London to mend his fortunes. The family continued in poverty, however, occupying a couple of rooms in a coach house in a London alley. Michael never went beyond the elementary grades in school. At the age of thirteen he was apprenticed to a London bookbinder, and he faced the prospect of working at a craftsman's bench for the rest of his life.

Faraday's early interest in scientific literature

Endowed with the boundless curiosity that is the hallmark of the true scientist, young Michael started to read some of the books he was binding; he was particularly fascinated by works on science. An article on electricity in an encyclopedia particularly delighted him. To satisfy his newly aroused curiosity, Faraday saved up enough money to pay for attendance at a course on "natural philosophy," as science was still called.

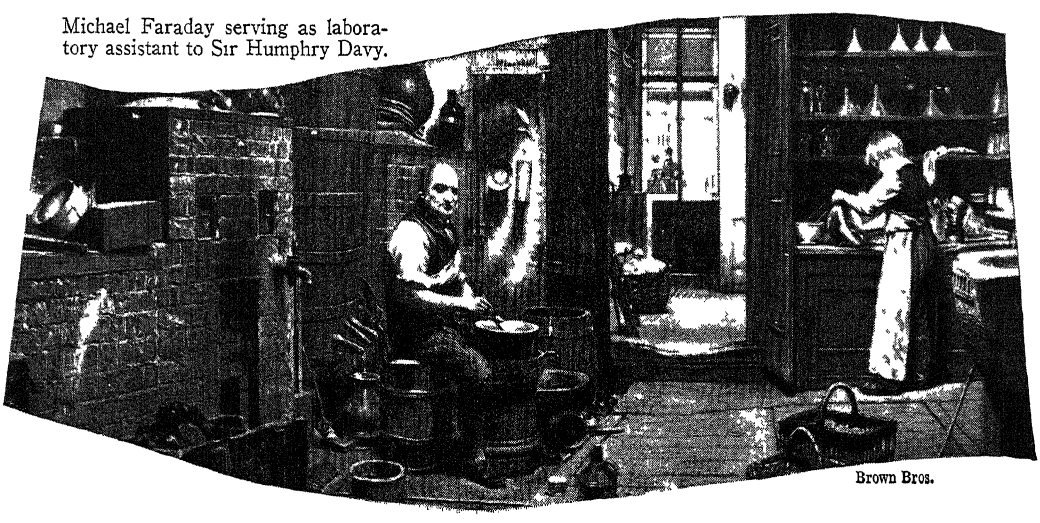
Then one of the patrons of the bookbinding shop, a Mr. Dance, who was a member of the Royal Institution, took the boy to hear some lectures by brilliant Sir Humphry Davy, director of the institution. Faraday was tremendously impressed by these lectures. He sat down and wrote to Davy, applying for a job and enclosing the careful notes he had taken on Davy's lectures "as proof of my earnestness."

A few days later a coach drew up at Faraday's humble home. A footman descended and handed the youth a letter from Davy inviting him to call at the institution. After a brief interview Sir Humphry offered Faraday a job as laboratory assistant for twenty-five shillings a week and a bedroom in the institution. Michael eagerly accepted. His duties included bottle-washing and other disagreeable chores; but the young assistant was enraptured. For he was now in everyday contact with the kind of scientific research that appealed to him above all things.

Davy quickly recognized Faraday's genius and gave him a hand up the ladder of success; he took the youth on a trip to the Continent and introduced him to many distinguished men of science. It is true that Davy never quite accepted Faraday as his social equal, and it is said that he became jealous of the scientific successes of his modest assistant. Yet, when asked to name his greatest scientific discovery, Davy promptly replied, "Michael Faraday."

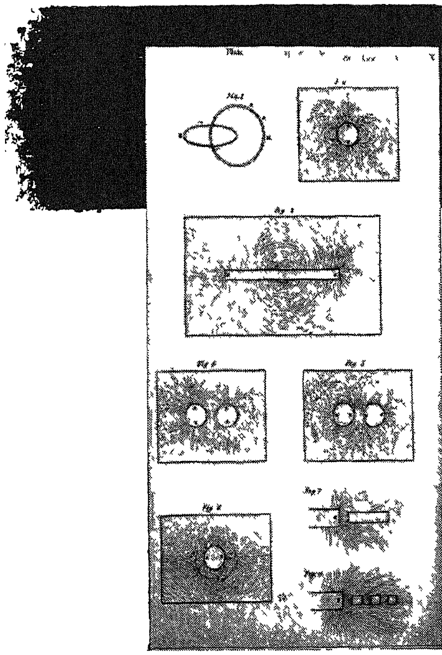
Faraday's life was spent in research and a certain amount of lecturing. In 1820 he married Sarah Barnard, a silversmith's daughter, who turned out to be a model of wifely devotion. Immediately after their marriage, the young couple came to live in rooms at the Royal Institution. In 1825, Faraday was made director of the laboratory. He became Fullerian professor of

Michael Faraday serving as laboratory assistant to Sir Humphry Davy.



Brown Bros.

Right. Michael Faraday. The drawings, which show lines of force, are from his *Experimental Researches in Electricity*



chemistry in 1833; but his salary remained £100 ($500) a year plus living quarters.

His advice was sought on many scientific problems and he might have earned large fees as a consultant; but, from 1830 on, he resolved to accept no outside work and to devote himself solely to pure science. He refused many honors that were pressed upon him — knighthood, professorships, even the presidency of the Royal Society. It was only after much urging that he finally accepted a government pension of £300 ($1,500) a year. When his memory failed him in later years, leaving him, as he said, "weak in the head" and "content to give lectures to children," he finally gave up his researches. He died quietly in 1867 at Hampton Court in a house given to him by Queen Victoria.

Faraday had the kind of mind that could reduce scattered observations of all kinds to the simple orderliness that is characteristic of all great scientific theories This trait was shown strikingly in his work on magnetic curves and electrical lines of force. He made it possible for the first time to visualize these "curves" and "lines." He did it by taking a piece of flat cardboard and scattering iron filings lightly over it He then put a straight magnet under the card. The iron filings immediately clung together in chains of characteristic shape The chains were thickest near the poles of the magnet and seemed to move in a wide loop on each side of the magnet from one pole to the other. By examining these patterns Faraday was able to throw light on what previously had been puzzling to investigators. He could now analyze the varying strength of electromagnetic forces; he could explain more fully Arago's experiments with the electromagnet and Ampère's theory of the forces in electric currents.

Oersted, Arago and Ampère had worked out the relationship between magnetism and electricity. But they had left out of their experiments and theories the significant factor of motion. Faraday recognized this factor; and as a result he made possible the practical development of electrical dynamos and motors. He showed that there is a "mutual relation of electricity, magnetism and motion." In a passage of his carefully kept diary, under date of March 26, 1832, he wrote:

"The mutual relation of electricity, magnetism and motion may be represented by three lines at right angles to each other

. . . If electricity be determined in one line and motion in another, magnetism will be developed in the third; or if electricity be determined in one line and magnetism in another, motion will occur in the third."

Arago had shown that an iron core set in a coil of wire acts like a magnet when a current is passed through the coil. In a classic experiment Faraday showed that the converse is also true — that a magnet can produce a current. He wound two separate coils of wire around an iron ring; one of these coils was connected with a battery, the other with a galvanometer (an instrument for measuring small electric currents by movements of a magnetic needle). Current was passed through the coil connected to the battery, and this magnetized the ring. The movement of the needle in the galvanometer showed that current was now induced in the secondary coil and without direct contact with a battery.

The forerunner of the electric dynamo

Later, Faraday mounted a copper disc between the two poles of a horseshoe magnet, so that the disc cut the magnetic lines of force. The axle of the disc and a point on its rim were connected to wires leading to a galvanometer. When the disc was made to turn at uniform speed, the galvanometer showed that the apparatus was producing a steady electric current. Here was motion producing electricity. This crude apparatus was the forerunner of the electric dynamo. It was the forerunner, too, of the electric motor, which is a sort of dynamo in reverse.

Faraday's discovery of the principle of the dynamo was to have momentous results, for the dynamo has made electricity fully available to all. The force of running water or the power of steam is used to turn the dynamos that transform motion into electricity. Through the use of copper-wire conductors and step-up and step-down transformers, electric power can be cheaply and conveniently transmitted to places that other forms of power could not easily feed. The modern household with its electric lights and its host of electrical appliances is an everlasting demonstration of the practical usefulness of Faraday's pure research.

Faraday made many other contributions to science. He showed that all substances have certain magnetic properties. He found that certain substances, like bismuth or glass, when exposed to powerful magnets, arrange themselves at right angles to the lines of magnetic force; he called such substances "diamagnetic." He gave the name "paramagnetic" to substances, like iron, that arrange themselves parallel to the lines of force.

Faraday's researches on the magnetic properties of light led to the discovery of radio waves. In 1845 he placed a block of glass between the poles of a powerful magnet and then passed a beam of plane-polarized light through the block along the direction of the magnetic field. He found that the plane of polarization was rotated as it passed through the glass. Exultantly he wrote: "I have at last succeeded in magnetizing and electrifying a ray of light and in illuminating a magnetic line of force." He advanced the theory that light waves might be transverse vibrations traveling along the lines of electric and magnetic force. Thus he pointed the way to the electromagnetic theory of light. As we shall see in another chapter, this theory was to be worked out later by James Clerk Maxwell, on the basis of Faraday's researches.

The study of electrolysis (chemical decomposition by the action of an electric current) attracted Faraday, and he made many notable discoveries in this field. He also introduced a number of terms that are still in common use. Thus he gave the name of "electrodes" to the wires or plates by means of which current is passed through a substance. He called the positive electrode the "anode" and the negative electrode the "cathode." He applied the name "electrolyte" to the body that is decomposed into different particles when current is passed through it; he called the particles "ions."

Though Faraday's electrical discoveries represent his chief contributions to science, he also did important work in chemistry. He made a special study of chlorine; he succeeded in liquefying chlorine and other

Smithsonian Institution

Joseph Henry, a pioneer in electrical research.

gases; he investigated gaseous diffusion. He studied the various alloys of iron, and he produced new kinds of optical glass. All in all, he was an early outstanding example of the men who make pure scientific research a profession.

Many of Faraday's electrical discoveries — including the induction of electric current — were made independently by the American physicist Joseph Henry, one of the great figures in the history of American science. In certain respects his life — particularly his early years — paralleled that of Faraday. He was born in Albany, New York, in 1797, of parents who had but recently come over from Scotland. His father died while Joseph was a young boy and he was sent to live with his grandmother. At the age of fourteen, the lad was apprenticed to a silversmith, who later failed. Henry then became interested in the theater and wrote several plays; he also organized a debating society.

One day a small book entitled Lectures on Experimental Philosophy fell into his hands; it completely changed the course of his life. In later years Henry wrote of the Lectures: "It was the first work that I ever read with attention. It opened to me a new world of thought and enjoyment; invested things before almost unnoticed with the highest interest; and caused me to resolve at the time of reading it that I would immediately commence to devote my life to the acquisition of knowledge."

Henry went to night school and then to the Albany Academy, supporting himself by teaching and by tutoring After a time he went off into the wilds of New York State to make an engineering survey. In 1826 he was made professor of mathematics and natural history at the Albany Academy and thenceforth settled down to a life of scientific research, teaching and administration. In 1832 he was called to Princeton University.

As the years went by, his scientific reputation grew. In 1846 he was appointed first secretary and director of the newly founded Smithsonian Institution in Washington, D. C. He devoted his energies to the institution for thirty years, almost until his death in 1878. Among other things, he succeeded in inaugurating a weather-report system at the institution and he directed its researches on the phenomena of sunspots and solar radiation.

Henry's achievements in electrical research

In the field of electrical research Henry has almost as many discoveries to his credit as Faraday. Had he published the results of his researches on induced current sooner, he might have won greater international recognition. Among his important discoveries in this field was the phenomenon known as self-induction, or self-inductance. He revealed, too, the nature of alternating current as contrasted with direct current.

Henry discovered that the power of the electromagnet is increased as more turns of wire are wound around its soft-iron core. Utilizing this principle, he proceeded to construct what he called an "intensity magnet," with many turns of fine wire. As we shall see, this apparatus made possible the electric telegraph. Henry built a number of exceedingly powerful electromagnets; one of them lifted a weight of some 3,300 pounds. Among the other electrical devices that he developed were high- and low-resistance galvanometers, a small electric motor and the first electric bell.

There were other prominent figures in this pioneer period of electrical research. The name of the English physicist Sir Charles Wheatstone (1802–75) is perpetuated in Wheatstone's bridge, a device for measuring electrical resistance. Invented by S. H. Christie in 1833, it was introduced to English scientists by Wheatstone, and that is why it bears his name. Wheatstone measured the velocity of an electric current in a conductor, made improvements in the dynamo and devised (with William F. Cooke) and patented in 1837 an electric telegraph. Nor were his discoveries limited to the field of electrical research; for he suggested the stereoscope, and he invented the musical instrument known as the concertina.

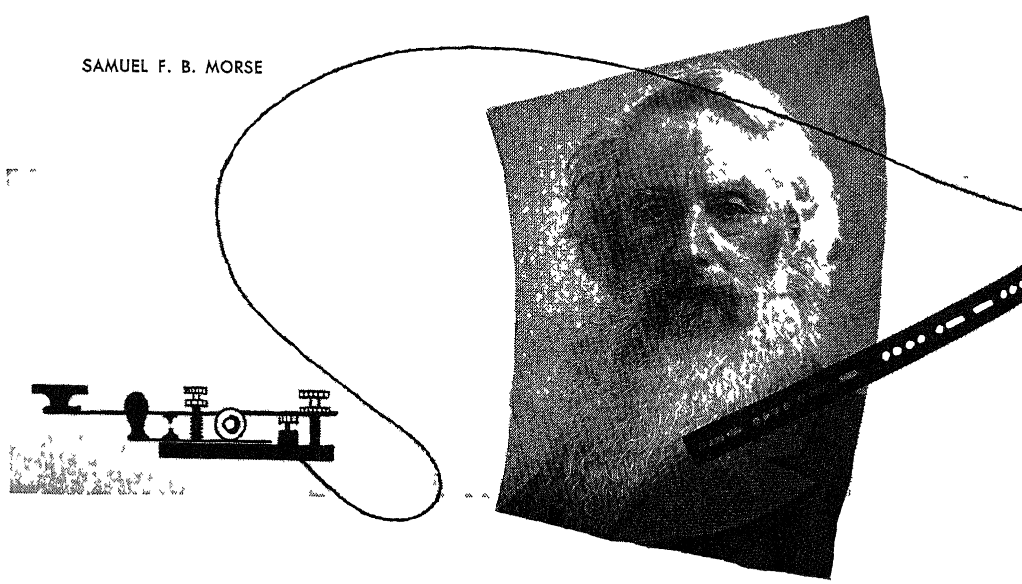
Another English scientist who followed up Faraday's work was James Prescott Joule. As we shall see, his most important work was done on the mechanical equivalent of heat. However, in a paper, The Production of Heat by Voltaic Electricity, he announced the important electrical principle known as Joule's Law: that the heat produced in a conductor is proportional to the resistance of the conductor, to the square of the current and to the time. This law applies to the heating elements of such devices as electric toasters, heaters and furnaces. Joule claimed that "there are few facts in science more interesting than those which establish a connection between heat and electricity."

By the end of the nineteenth century the science of electricity had attained its maturity. Long before that time, ingenious men had begun to apply electricity to the everyday practical problems of mankind. We shall now see how this was done.

ELECTRICITY GOES INTO ACTION

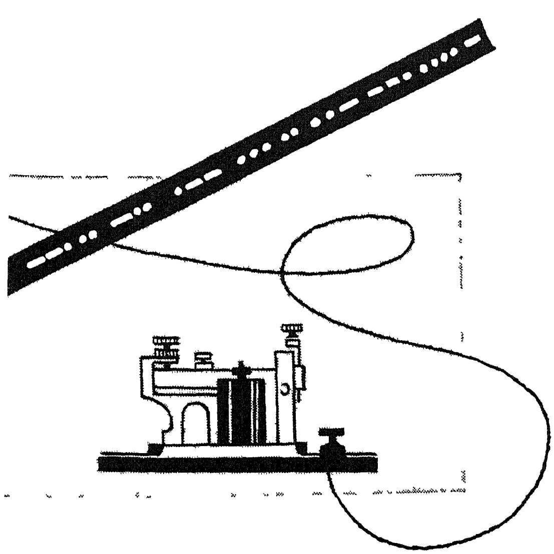
Toward the middle of the nineteenth century, electrical "toys" came out of the laboratories of research men and became practical devices that reshaped civilization. Electricity in action first of all brought *rapid communication* — the telegraph, the undersea cable, the telephone, the wireless telegraph. Soon it also brought *illumination* — the arc light and the electric bulb — and *transportation* — at first the trolley car in place of the horse car. When direct and alternating dynamos made the use of electricity safe, convenient and practical, there came into being electric-welding processes, cheap aluminum and thousands of devices, like switches, current meters, fuses and circuit-breakers.

Electricity in action represented the practical application of theories that had been developed by pure scientists like



Ampère and Faraday. Its usefulness depended on the genius of inventors and engineers. This placed a premium upon mechanical ability and imagination; it opened an era of "tinkering" that achieved particularly spectacular results in the United States. Although Europe contributed a good deal, American inventors (and businessmen) did most to improve electrical apparatus and to get the electrical age under way. The three outstanding inventors of electrical apparatus in this era were Samuel Finley Breese Morse, father of the telegraph; Alexander Graham Bell, who gave us the telephone; and Thomas Alva Edison, "the wizard of Menlo Park," whose thousand-odd inventions included the phonograph and the incandescent electric lamp.

Before the invention of the telegraph, the news of the world traveled slowly. As late as 1815, the British and Americans fought the Battle of New Orleans because they had not received word that the peace of Ghent, ending the War of 1812, had been signed two weeks before. Some attempts had been made in the eighteenth century to devise telegraph systems using Leyden jars and static electricity, but these attempts were all failures. In the days of the French Revolution a system of semaphore signals — a so-called optical telegraph — was constructed by the brothers Claude and Ignace Chappe, and it worked fairly successfully. In this device crossbars set at the top of poles were manipulated into different positions to indicate the different letters of the alphabet. The poles were placed atop hills, which came to be known as "telegraph hills." Between 1796 and 1816 the British Admiralty operated an optical-telegraph line that carried messages from London to Dover in seven minutes. At that time the fastest — but by no means the surest or the most convenient — way to send messages over reasonably long distances was by carrier pigeons. London got its news of Waterloo in that way.



The practical electric telegraph had to await the development of current electricity and of the electromagnet. When Samuel Finley Breese Morse (1791–1872) set out to invent a practical system of electrical telegraphy in 1832, the electric current and the electromagnet were available. Morse also possessed the vital information that when you break an electric circuit in one place, the current stops at all places in the circuit. This is the basic principle of the electric telegraph.

Morse had been trained as a painter, but he was not a very successful one. He was on his way home from Europe in 1832, aboard the packet boat Sully, when he met a Bostonian, Dr. Charles T. Jackson, who was interested in electromagnetism. The good doctor had just been in Paris and was brimful of information about experiments that he had seen Ampère perform. He aroused the artist's curiosity by showing him an electromagnet. Very quickly, as Morse fingered the instrument, the idea of the telegraph came to him. He went to his cabin and sketched out its basic details: the electromagnet whose circuit is intermittently broken by means of a key, and the system of short and long breaks — "dots" and "dashes" — that became the Morse code of signals.

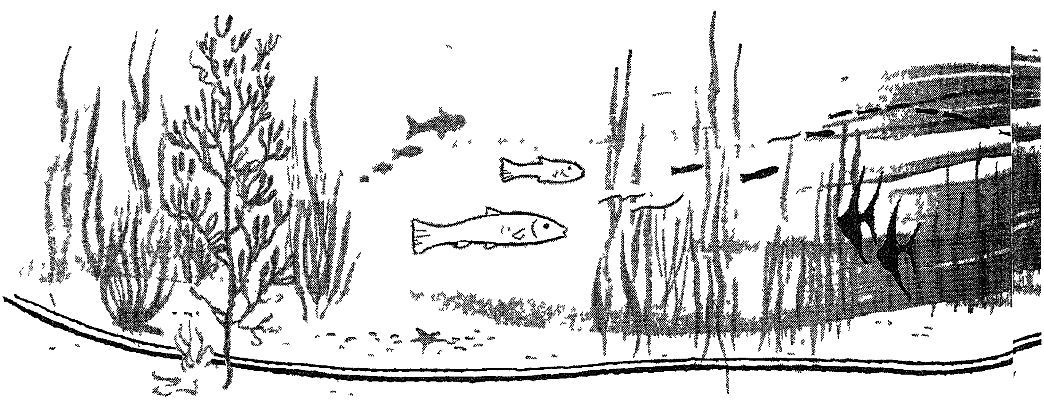
While he was perfecting his telegraph, Morse taught art. In 1835 he was appointed professor of art and design at the newly established New York University. Here he came in contact with Leonard Dunnell Gale (1800–83), professor of chemistry, who helped Morse overcome some of the

difficulties that kept his telegraph from working Among other things, the current transmitted through the wire had proved too weak to operate the kind of electromagnet that Morse was using. Gale told the inventor about Joseph Henry's finely wound intensity magnet. This apparatus solved the problem. Morse devised a relay circuit in which the weak signals over the line were picked up and made audible in clicks of the electromagnet bar by means of a strong local battery circuit.

In New York, Morse also met a young man, Alfred Vail, who became fascinated with the possibilities of Morse's instrument. Vail and his father offered Morse financial aid in completing his experiments; their first investment came to $2,000. By 1836 Morse had built an electric telegraph that really worked. He made formal application for a patent in the United States in 1838, but it was not granted until ten years later.

In the meantime Morse's public demonstrations of the telegraph aroused but little interest; hard-headed businessmen were not ready to invest in electrical "toys." Finally Morse approached the Congress of the United States and asked for an appropriation to construct an experimental telegraph line. Many of the lawmakers in Washington thought Morse a visionary and a fanatic; they feared that a host of "crazy inventors" would descend upon them if they gave him funds. A few, however, saw the light; in fact, one congressman resigned his seat to become a partner in the telegraph enterprise. At length, in 1843, Morse got an appropriation of $30,000 to build a telegraph line from Washington to Baltimore

The construction of his first telegraph line, done under the supervision of Ezra Cornell (founder of Cornell University), ran into difficulties. At first it had been decided to place the wires underground. Two-thirds of the money that had been appropriated was spent before it was found that this system would not work. In desperation Morse accepted Cornell's idea of stringing the wires on poles and insulating them from the wood by means of glass bottlenecks. The scheme proved to be successful. On May 24, 1844, Morse in Washington telegraphed to Vail in Baltimore the famous first message sent by the electromagnetic telegraph. His words were: "What hath God wrought!"



On that day it so happened that the Democratic National Convention was sitting in Baltimore. Vail telegraphed to Morse that the convention had nominated Silas Wright of New York as vice-president. Morse took this message to the nominee, who was then in Washington. Wright told Morse to telegraph the convention that he could not accept the nomination. When Vail brought this message to the delegates, they thought it was a fraud. They dispatched a delegation to Washington to have a talk with Wright and he confirmed in person what he had reported in the telegram: he would not accept the nomination. This incident brought quick confidence in Morse's new invention

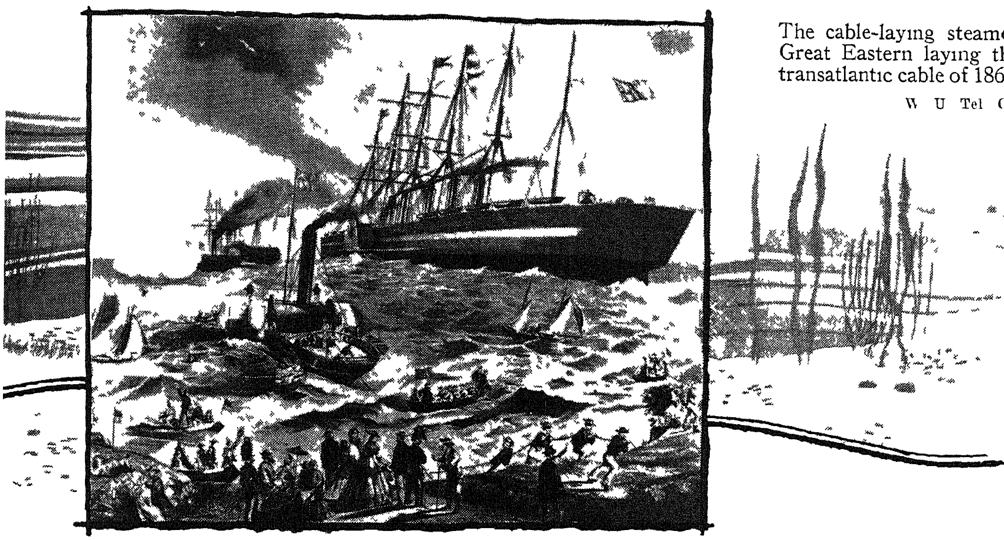
Many telegraph companies were

formed, infringing on Morse's patents; but, after much litigation, his rights were upheld In 1856, under the leadership of Hiram Sibley, the Western Union Telegraph Company was formed. Its success finally gave Morse the prosperity he deserved after so many years of penny-pinching effort. Many honors and decorations came to him; his bust is in the American Hall of Fame.

Overland telegraphy had no sooner been demonstrated by Morse than underseas electrical communication, connecting continents, became the new dream. Submarine cables, extending for short distances offshore, were soon in use. But the world was waiting for a cable that would span the Atlantic Ocean and put the Old and New World in almost instantaneous communication. Cyrus West Field (1819–92), a New England paper merchant and business promoter, undertook to lay the first Atlantic cable and organized a company for this purpose in 1854. Cable-laying was begun in 1857 and completed the next year; on August 16, 1858, Queen Victoria and President Buchanan exchanged messages.

But Field's triumph was short-lived, for in a few weeks the cable went dead. It was soon discovered that it had burned out. Faraday had warned that the insulated wire, surrounded by sea water, would act like a gigantic Leyden jar, the currents charging the condenser would slow down and weaken the transmission of electrical impulses. In order to get messages across the ocean, the electricians who had worked on the 1858 cable had used such high voltages that the insulation had been burned off the wires Furthermore, the copper wire and the insulation were not up to the manufacturing standards necessary for success

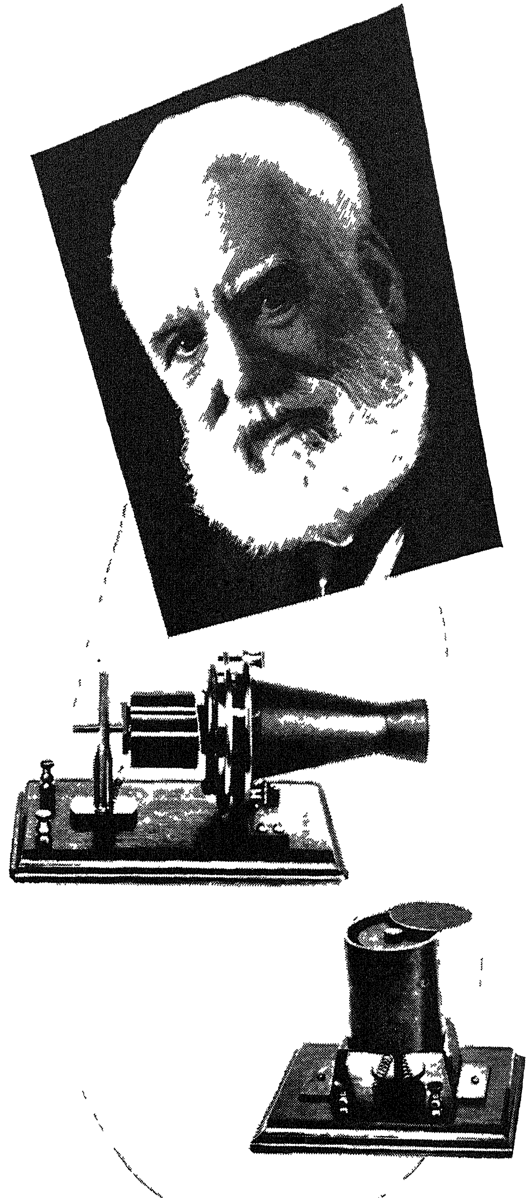
The American Civil War intervened, and cable-laying was abandoned It was taken up again in 1865, after the war had come to an end. This time the new technical expert, William Thomson, made sure that the materials he ordered were up to engineering specifications. The cable-laying boat, the Great Eastern, left the port of Valentia, Ireland, on July 13, 1866, and arrived at Newfoundland, its mission accomplished, on July 28. Queen Victoria and President Andrew Johnson exchanged greetings; excitement ran high in torchlight processions in London and New York. Thomson was knighted. The honor was well deserved, for an invention of his — the mirror galvanometer — had meant the difference between success and failure.



The cable-laying steamer Great Eastern laying the transatlantic cable of 1866

W U Tel Co

The mirror galvanometer was a sensitive instrument in which a small mirror with tiny magnets on its back was suspended between coils of fine wire. A beam of light



A T. & T.

Alexander Graham Bell in later life. Below: replicas of the magnetic transmitter and receiver exhibited in 1876.

was focused on the mirror, which reflected the light onto a screen. When the current moved through the cable in one direction, producing "dots," the mirror swung one way; when the current was reversed, producing "dashes," the mirror swung the other way. Watching the screen, the operator noted the "dots" and the "dashes" and took down the message. In the following year — 1867 — Thomson perfected another recording instrument — the siphon recorder — which gradually replaced the mirror galvanometer. The workings of this instrument are described on page 802.

Thomson, who later became Baron Kelvin, made a fortune out of his inventions. In addition to the cable recorders, they included a short-needled mariner's compass, a tide-predictor and (with Henry C. F. Jenkin) a curb transmitter.

Born in Belfast in 1824, son of a university professor, Thomson received an excellent university education at Cambridge and Glasgow. He was appointed a professor at the University of Glasgow in 1846, at the age of twenty-two, and he held that post for fifty-three years. While at Glasgow he turned an old coal cellar into one of the finest teaching laboratories in the world. He died in 1907.

Thomson did much first-rate work in pure science; he contributed particularly to the development of electrodynamics and thermodynamics. He was among the first to recognize the value of artificial refrigeration and low temperatures for the preservation of food (hence the trade name Kelvinator). He developed an "absolute scale" of temperature — the Kelvin scale — in which the zero mark is set at minus 273.1°C. (see page 166).

World-famous as a distinguished and energetic scientist-inventor, Thomson was invited to serve as a judge at the Philadelphia Centennial Exhibition in 1876. In company with Dom Pedro, the Emperor of Brazil, Thomson visited an out-of-the-way little booth where an obscure inventor was carefully displaying his own new electrical device. At the invitation of the inventor Dom Pedro picked up the apparatus and put it to his ear. "My God!" he exclaimed, "It talks!"

"This is the most wonderful thing I have seen in America," was Sir William's excited comment when he examined the instrument. Following these endorsements, the instrument, which was called a telephone ("far sounder") was given a prominent place at the exhibition, and its inventor,

Alexander Graham Bell (1847–1922), leaped overnight to fame.

Bell was a Scotchman who had moved to Canada in 1870. In the following year he had come to the United States as a teacher of a system of "visible speech" for the deaf. This system had been devised by his father; in fact Bell's family had been interested in human speech and elocution for several generations. "I now realize," said Bell, many years after he had become famous, "that I should never have invented the telephone if I had been an electrician. What electrician would have been so foolish as to try any such thing? The advantage I had was that sound had been the study of my life — the study of vibrations."

Hundreds of inventors had tried to develop a telephone that really worked. However, as was brought out in patent trials over the "most valuable single patent ever issued" (in 1876), no one before Bell had ever made an instrument that actually talked, in court or out of it. Among those who claimed the invention of the telephone were Daniel Drawbaugh, an American inventor, who filed patent papers the same day as Bell; Elisha Gray, another American, who, according to Bell, came closest to inventing the telephone of all the men who had worked on the project and who had not succeeded; and Johann Philipp Reis, a German physicist, who displayed an unsuccessful instrument for electrical transmission of the human voice in 1869. It was Reis who first used the word "telephone." Joseph Henry had been interested enough in Reis's apparatus to try to find out why it failed to work.

Bell's interest in telephony had been awakened when Sir Charles Wheatstone called his attention to the fact that the German physicist Hermann von Helmholtz had vibrated tuning forks by means of electromagnets. Bell now conceived the idea of a "musical telegraph," which would send a number of messages over a single wire at one time. He was working on this device in a Boston attic with a young assistant, Thomas A. Watson, when he stumbled on the secret of the "talking telegraph," or telephone. Watson has told the story, thus:

"On the afternoon of June 2, 1875, we were hard at work on the same old job, testing some modification of the instruments. Things were badly out of tune that afternoon in that hot garret — not only the instruments, but, as I fancy, my enthusiasm and my temper, though Bell was as energetic as ever. I had charge of the transmitters, as usual, setting them squealing one after the other, while Bell was retuning the receiver springs one by one, pressing them against his ears. . . .

"One of the transmitter springs I was attending to stopped vibrating and I plucked it to start it again.

An "accident" leads to the development of the telephone

"It didn't start and I kept on plucking it, when suddenly I heard a shout from Bell in the next room. Then out he came with a rush, demanding: 'What did you do then? Don't change anything. Let me see!'

"I showed him. It was a very simple thing. The make-and-break points of the transmitter spring I was trying to start had become welded together; so that, when I snapped the spring, the circuit had remained unbroken while that spring of magnetized steel, by its vibrations over the pole of the magnet, was generating that marvelous conception of Bell's — a current of electricity that varied in intensity precisely as the air was varying in density within hearing distance of the spring. . . . The right man had that mechanism at his ear during that fleeting moment, and instantly recognized the transcendent importance of that faint sound thus electrically transmitted."

Forty weeks of feverish activity followed the discovery of that clue. Instrument after instrument was constructed and discarded. Then, on March 10, 1876, Bell uttered and Watson heard the first words ever spoken over the telephone: "Mr. Watson, please come here. I want you."

A few months later came the famous demonstration at the Philadelphia Centennial Exhibition. But the public was reluctant about purchasing and installing telephones. Bell's father-in-law, Gardiner

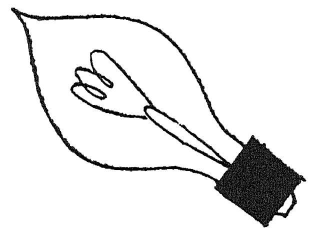
Hubbard, a Boston lawyer, undertook to organize a Bell Telephone Association. Small exchanges were set up in New York, New Haven, Bridgeport and Philadelphia, but subscribers were few. The telephone served at first chiefly as a burglar-alarm system; the telegraph was supposed to be good enough for those who wished to communicate over long distances. Then a Wall Street brokerage house asked the Western Union Telegraph Company to take out its printing telegraph instruments and to install telephones instead. This started a great financial, legal and technical battle between the telegraph and telephone companies. But Bell and his associates soon triumphed and the usefulness and value of the telephone were quickly established.

Improvements in telephones and in telephone service

Great feats of electrical engineering were required to perfect the telephone instrument and to improve telephone service. Central exchanges and switchboards were among the first problems that had to be solved. One of the pioneers in this field was Colonel John J. Carty, who practically created the profession of "telephone engineer." Then came the problems of long-distance lines, automatic dial telephones, wireless telephony and hundreds of others.

The first transcontinental telephone line, from New York to San Francisco, was opened in 1915. To celebrate this event, Bell repeated to Watson, three thousand miles away, the historic words of the first telephone conversation: "Mr. Watson, please come here. I want you." Watson laughingly answered: "It would take me a week now": that is, to reach Bell. If that response were given today, it would be all wrong; for the development of the airplane, to which Bell made important contributions, now makes it possible to span the continent in less than a day.

The next step in world-wide electrical communication was the development of wireless telegraphy during the 1890's. In time the wireless was hitched up with the telephone, the loud-speaker and other inventions to become our modern radio. We shall tell the exciting story of this development in later chapters.



Early model of Edison's electric lamp.

The advances in rapid communication had a most important effect on the further development of science itself. It broke down the geographical isolation between scientists; with the help of improved printing presses, it allowed for quicker exchange of scientific information between countries and continents. No longer would a Joseph Henry have to repeat a Faraday's "unknown experiments."

The communication arts were further advanced through the efforts of one of America's greatest inventors, Thomas Alva Edison (1847–1931). He improved the telegraph by the invention of "quadruplex telegraphy," an automatic telegraph repeater, a printing telegraph, a system of telegraphy for communicating with moving trains and scores of other devices. He invented a carbon transmitter for Bell's telephone. Among his other inventions were the motion-picture camera and reproducing machine, originally called the kinetoscope, the mimeograph, an electric pen, an electric vote-recording machine, the microphone, the electric valve, the magnetic-ore separator, a new process for making portland cement, improved electric dynamos and motors and — perhaps the most important of all — the incandescent electric lamp. "All things," said this tireless inventor, "come to those who hustle while they wait."

Edison was born in Milan, Ohio. He grew up in Port Huron, Michigan, where he failed to distinguish himself in school. His chief delight was to putter around in a "laboratory" in his mother's attic. At the age of twelve he went to work as a newsboy and candy "butcher" (vendor) on the

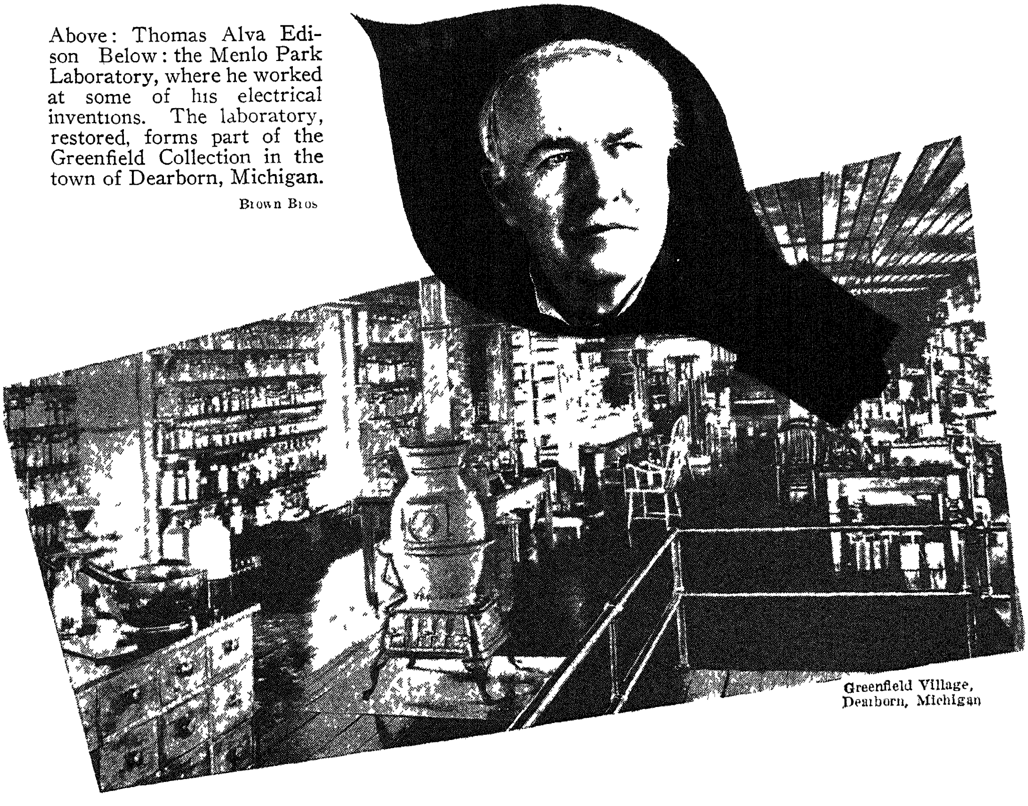
Grand Trunk Railway running into Detroit. He continued his experiments in the baggage car that contained his supplies until he accidentally set fire to the car. A short time before, he had saved the life of a child along the railroad right of way. Out of gratitude, the child's father, the stationmaster at Mount Clemens, Michigan, arranged to have the youth take lessons in telegraphy. Edison soon became an expert operator. For a time he led the carefree, impecunious life of a wandering telegrapher, working in various cities in the United States and Canada.

He lost his first job as a night operator because he was found asleep at his post. He had shown his mechanical ingenuity while on this job by rigging up a clock device that sent automatic signals down the line regularly every half hour while he was sleeping. Later, he won a certain amount of local fame in Boston by constructing an electric-wire barrier; this apparatus electrocuted cockroaches that were after his lunch. In 1869 the young man arrived in New York with but a dollar in his pocket and great inventions in his head.

Almost immediately, however, he got a job at what was then the princely salary of $300 a month, and this marked the turning point of his career. This is how it happened. He had wandered into the offices of a Wall Street company whose business it was to supply stock quotations to brokers' offices by means of an elaborate telegraphic system. That day the central telegraph had broken down. Every broker in Wall Street immediately sent a boy to the office to see what was wrong; soon two hundred youngsters were shouting questions at the harassed superintendent. Edison said that he could fix the broken machine in a few minutes, and he was as good as his word. The repair was simple enough; it consisted of replacing a contact spring that had fallen between two gear wheels. Edison was hired to take

Above: Thomas Alva Edison Below: the Menlo Park Laboratory, where he worked at some of his electrical inventions. The laboratory, restored, forms part of the Greenfield Collection in the town of Dearborn, Michigan.

Brown Bros



Greenfield Village, Dearborn, Michigan

charge of the office. Very soon, in his spare time, he invented and patented an improved type of stock ticker. The company for which he was working purchased this contrivance for $40,000; later he admitted that he had planned to ask for only $5,000.

With the money from this invention, Edison opened an "inventor's workshop" in Newark, New Jersey. It was removed to Menlo Park, New Jersey, in 1876 and to West Orange, New Jersey, in 1887. In one or another of these workshops Edison's great inventions were made, one often flowing from another. His work on the telephone transmitter, for example, had shown him how a vibrating diaphragm would take up sound waves. Quickly he sat down and sketched a model for recording these vibrations on a wax cylinder. His model-maker, John Krusei, working for thirty solid hours, turned out a working model. It was the first phonograph. Slowly turning the crank of the machine, Edison spoke into it and then played back the first words ever put on a phonograph record: "Mary had a little lamb."

Edison invents the incandescent electric lamp

In 1879 Edison invented the incandescent electric lamp. The most effective electric illuminating device up to this time had been the carbon arc, or "electric flame," which had been discovered by Sir Humphry Davy in 1807. This "electric aid to navigation" had been installed in a famous old lighthouse at Dungeness, off the coast of England. Arc lights had appeared — mainly as a curiosity — on the streets of London and Paris in the 1860's. In the 1870's Charles F. Brush of Cleveland had so improved arc lighting and its power plant that cities and stores — John Wanamaker's in Philadelphia among them — began to install the lights. Brush's two chief innovations were the copper plating of the carbon rods and the attaching of a control magnet that kept the lights in a circuit burning even after one of them had gone out. Yet there were various objections to the carbon arc light. It was so brilliant as to be almost blinding; it could not be turned down low like the gas lights then in use. "The electric light cannot be subdivided," said the experts.

Edison was invited by Professor George F. Barker of the University of Pennsylvania to try his hand at the solution of this problem. Instead of trying to "subdivide" the carbon arc, he perfected a new kind of light. The carbon arc operates by actually consuming the particles of carbon that move through the gap between its points. The incandescent lamp works on an entirely different principle. In a glass globe from which the air has been exhausted, a slender filament is heated to incandescence — white heat — by the passage of an electric current.

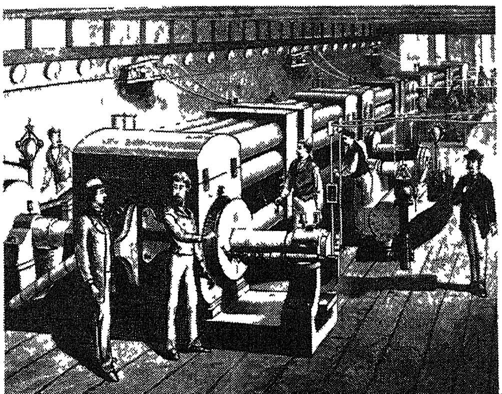
Filaments for electric lamps

Edison's chief task was to find some material suitable for the filament — something that would glow brightly, yet not burn up too quickly. The inventor tried everything he could think of, starting with platinum wire. At last, in October 1879, he found the first thing that really worked as a filament; it was a piece of cotton thread, burned to a crisp — that is, carbonized. Further investigation, which sent men to scour the tropical jungles, showed that the best carbon filament then obtainable could be produced from a bamboo tree that grew in the Amazon Basin. Edison soon began the manufacture, at a loss, of carbon-filament bulbs that would burn a hundred hours. The electric light bulb has since been greatly improved with better filaments (tungsten wire, for example) and tighter sealing. But it still operates on Edison's principle.

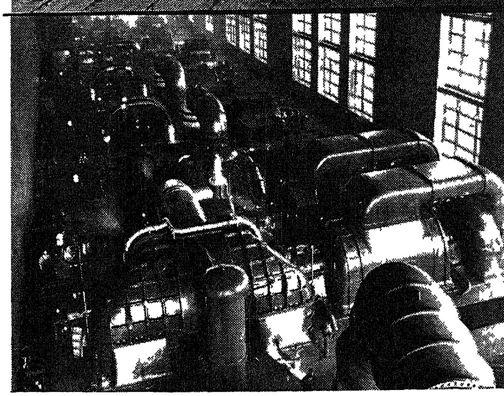
Elihu Thomson (1853–1937), known to many as "the beloved scientist," was, like Edison, a prolific inventor; he took out more than seven hundred patents in all. Among his inventions were electric welding, the three-phase alternating-current generator, the common electric meter for measuring watts, and the centrifugal cream separator. Brought to America from Manchester, England, as a boy, Thomson soon showed remarkable aptitude for the inven-

tion of electrical apparatus. His companies, which later merged to form the General Electric Company, fought many patent and commercial battles with Edison's companies. "I wish sometimes that Elihu was not in any such uncertain business as the electric light," wrote his wife to her mother. "Just as soon as it succeeds, the money all flows away in litigation."

The development of the electric light and other electrical equipment led the way



This electric generating station first went into operation in the year 1882.



Modern electric generating plant, with a capacity of over 600,000 kilowatts.

Photos, Consol Edison of N Y.

to advances in the supplying of electric power. Up to that time the chemical battery had usually sufficed for electric-current requirements. But it took far greater power than this to operate all the electric bulbs that began to be used in increasing numbers. The electromagnetic machine called the dynamo now came into its own.

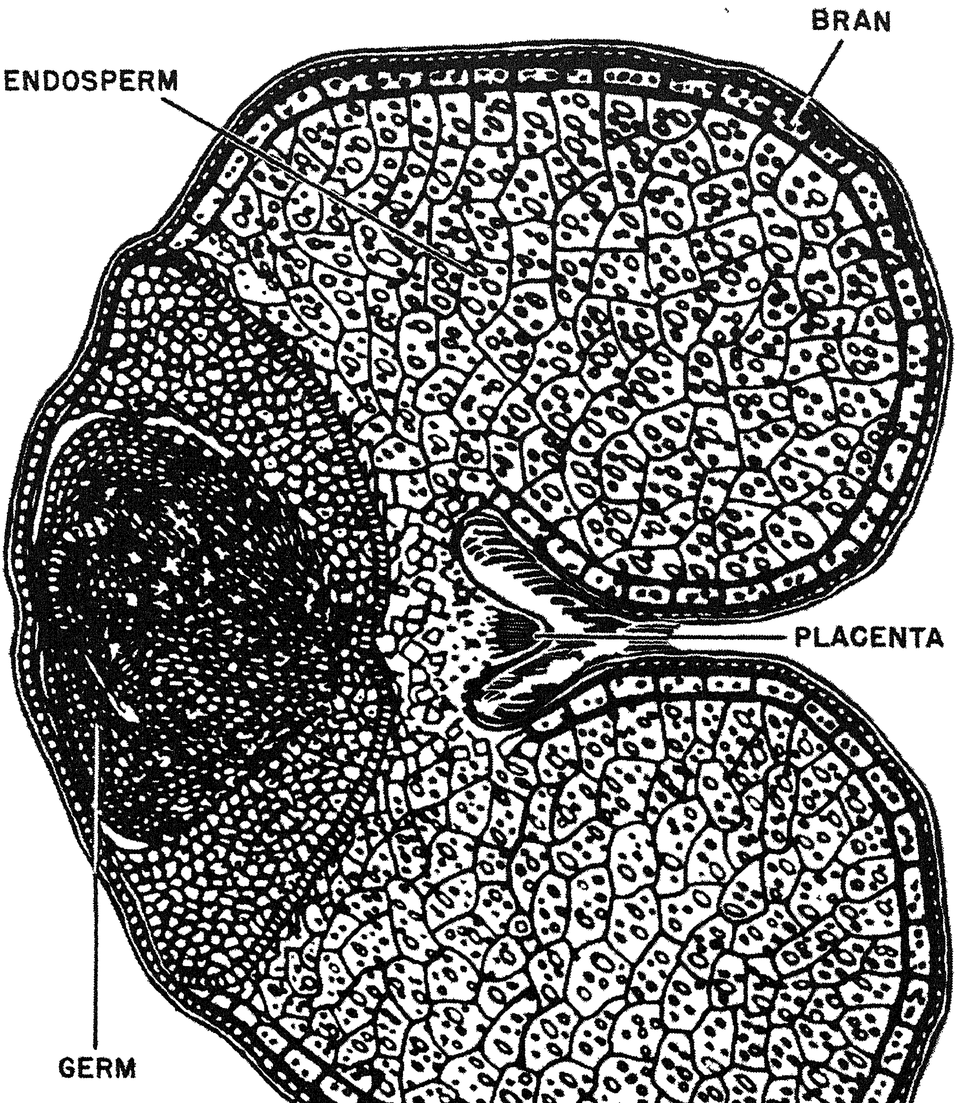
Faraday had developed the first experimental dynamo, as we saw, by revolving a copper disc between the two poles of a horseshoe magnet. H. Pixii, in Paris, produced an alternating-current machine in 1832 by rotating a permanent horseshoe magnet beneath a pair of fixed coils. In 1860 Antonio Pacinotti and Sir William Siemens introduced "commutators" — devices attached to the shaft of the dynamo and making it possible to deliver a steady stream of direct current. Zénobe-Théophile Gramme built the first efficient industrial dynamo. Like the telephone, it was displayed at the Philadelphia Centennial Exhibition, where it was seen by Elihu Thomson and Charles F. Brush. They immediately designed an even better dynamo for running street arc-light systems.

One of the first central power stations, in Pearl Street, New York, was built by Edison for his newly organized Edison Electric Light Company. The dynamos in this Pearl Street station were 90 per cent efficient; they had been designed by Francis Upton, one of Edison's assistants. The gas companies, Edison's competitors, sneeringly referred to the dynamos in this station as "long-waisted Mary Anns." They tried to prove that electric lights were dangerous, but the public was not impressed by this warning.

With electricity piped into homes, the way was open for devices that make use of fractional horsepower motors — vacuum cleaners, egg beaters and the like — as well as for other inventions that apply the heating effects of the electric currents — stoves, toasters and heaters. The demand for electric power, both for home and industrial use, quickly mounted. This led to the installation of mammoth hydroelectric plants, such as those at Niagara Falls, in which water power is used to turn turbines that generate electricity. A new era in the history of man's civilization — the electrical age — had been inaugurated.

SCIENCE THROUGH THE AGES is continued on page 2359.

THE WORLD'S GRANARY IN A GRAIN



Wheat Flour Institute

Cross section of a grain of wheat, highly magnified. The germ, at the left, is the embryo of the plant in its early stages. The endosperm represents tissue in which food is stored. This food is digested and absorbed by the embryo either before or after it germinates. Note the large amount of space taken up by the endosperm

PLANTS AS STOREHOUSES

How Plants, by Garnering Rich Foodstuffs for Their Own Progeny, Feed Mankind

WHERE PLANT-FOOD IS ACCUMULATED

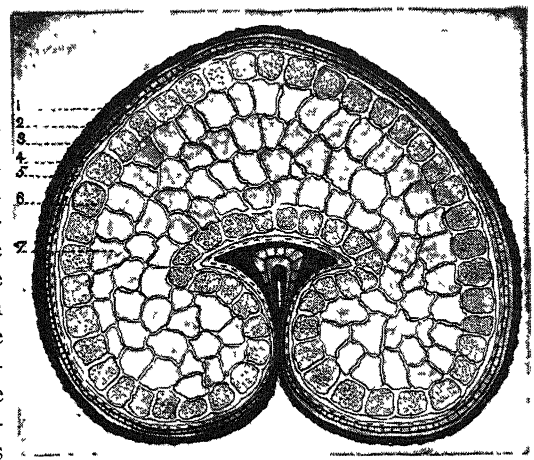
THE search for food must ever be a problem of vital importance to living organisms, but it becomes a more urgent need in the case of plants as compared with animals, inasmuch as the former are without means of locomotion Their area of food supply is limited; and it therefore is of the more importance that there should be some means devised by which the plant can store up nutrition over and above that required for present needs. Not only is storage of food required for the plant itself, but it is essential to the embryos of the plant, which as compared with animals again, are still more dependent upon some sort of provision for nourishment in their earliest stages.

In our last chapter we saw that in the class of plants to which the bean belonged ample provision is made for the nourishment of the young embryo in the seed-leaves, or cotyledons. These structures play such an important part in the storage of plant food that we must devote further attention to them. As we shall see, they are by no means all like those we have studied in the bean.

Their function, in the first place, is to provide the primary axis, or embryonic stem, with food. This primary stem, it will be remembered, consisted of the radicle, which grew definitely downwards, and the plumule, growing as definitely upwards. Neither of them at first is capable of getting food for itself, though in the course of time the radicle will throw out root-hairs, and will otherwise develop its capacity as a food-searcher, while the plumule will grow into the stem, and develop leaves that will bear their part also in the general life and nutrition. All this, however, is in the future, and in the meantime food there must be for the growth of these organs. Now, so long as the radicle and the embryonic stem are enveloped within the seed-coat, and, indeed, for some time afterwards, they are functionless, in so far as they cannot absorb inorganic foodstuffs from the soil, and are also utterly incapable of transforming these into organic compounds. Nevertheless, as we saw in studying the processes of nutrition, both organic and inorganic substances are required for growth. Not until the radicle has become a root in the true sense of the term, and not until true green leaves have developed from the stem, can the nourishment of the young plant be said to be independent. Until that stage is reached, life is dependent upon previously stored nutrition; food that has been assimilated and carefully deposited within the seed; food derived from the maternal plant; substances which, as regards their actual nature, are composed of starch, fat and proteids, all carefully guarded for the benefit of the embryo.

The storage chambers are, in most cases, the cotyledons. In their cells this supply of reserve material has been packed away until the needs of the growing embryo have made themselves felt. Without them the radicle and the stem would fail to grow, as can be proved by cutting away the cotyledons, when these two structures die from starvation. Special storehouses besides the cotyledons are sometimes formed within the seed-coat, and these, too, contain similar starches, and fats, and proteids, the whole forming the endosperm.

When the germination begins in such a condition, the two cotyledons are seen to increase in length, and to come into contact with this reserve store of food; and it would appear that their function in this case is a special one in connection with absorption. They stand in the position of the middleman in reference to the consumer. They, in the first instance, take up the stored food elements which have been themselves dissolved in the reserve tissue. This dissolving is also sometimes due to the cotyledons themselves. Then the cotyledons act as distributors, taking away the organic compounds from the storage area. It sometimes happens that only a portion of the cotyledons is enabled to act as an absorber of this food, as is the case in the onion, where the special cells required for this purpose are only developed at the end of the cotyledons. In this plant, after the cotyledon has absorbed the stored-up food by means of its own apex, it leaves the cavity of the seed-coat, and assumes a green character, acting in the same way that an ordinary leaf does. Here we have a bulb which has arranged on its stem a number of thick, fleshy folds, or leaves, lying over each other. The bases of these leaves form the main bulk of the "onion", the leaves thinning out as they reach the stem. After the full growth is over in summer, the green portions wither away, and their inferior parts form a protection for the rest of the bulb.



TRANSVERSE SECTION THROUGH A GRAIN OF WHEAT
1, epicarp; 2, mesocarp; 3, endocarp, 4, testa, 5, seed coat, 6, cells containing aleurone grains, 7, cells containing starch grains

LONGITUDINAL SECTION OF THE GROWING EYE OF A POTATO

Should such a bulb be kept until the succeeding year, and then planted again, it forms a new set of roots, produces leaves, and an inflorescence which is familiar to all of us when an onion is going to seed. Now, this second growth is dependent for its food supply upon the nourishment stored away in the bulb scales. All this nourishment is used up when the flowering stem is produced; and when the seeds have become ripe, the plant, having nothing more to live upon, dies. The first onion was an annual; the second one, biennial. Sometimes, however, there is no inflorescence formed, but merely shoots like leaves, which themselves form small bulbs, just as an onion seedling does; and these small bulbs are available for perpetuating the life of the plant after the parent plant has died down. In this case the onion becomes a perennial. This variation in the growth of the onion plant, made possible as it is by the different methods of storage and the variety of storage organs, introduces us to the terms "annuals", "biennials" and "perennials", in connection with plant life, and these must be clearly understood before we proceed further.

An annual plant is one which germinates, grows, and finishes its processes of flowering and fruiting within the limits of one single year, and it dies away if its seeds become ripe. That being the case, it is not surprising that annual plants concentrate their energies on the production of

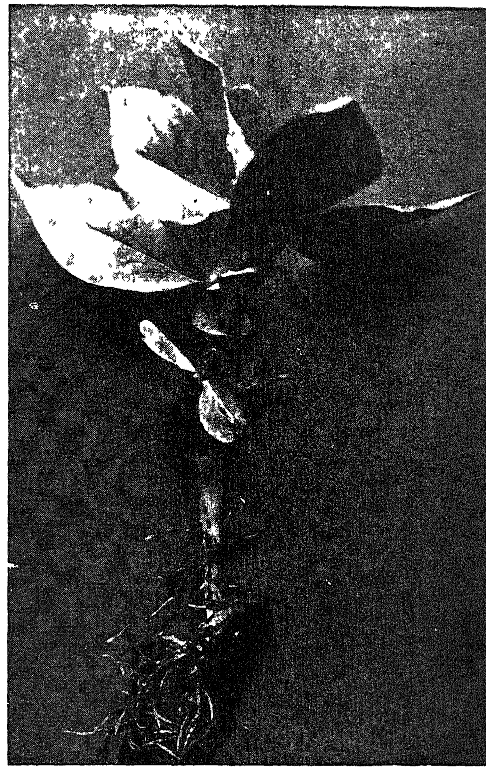
large quantities of seed. The largest annual plants are found in the castor oil group, and in some of the balsams. Usually the whole season, from spring to autumn, is required for an annual to produce its seed, though some of them, of which the common groundsel is an example, produces seed in a few weeks and may even produce a second and third crop in one season.

Biennial plants are those which, beginning as seedlings in one season, produce during that single season only roots, stem and leaves, but neither flowers or seeds. They then undergo a rest stage during the winter, resuming growth in the following spring, and now develop a stem which in this second season bears both flowers and seeds; and when the latter have reached a condition of ripeness the plant dies. Since the process takes two years, the plant is termed "biennial". The parsnip is an example of this.

Plants requiring more than two years before they produce flowers and seeds, or that live as individuals for a period of more than two years, are termed "perennials".

The question of the annual, biennial and perennial habit of life among plants is very intimately connected with the problem of the storage of nutrition. And if a plant dies down at the end of a summer season, and reappears the following spring as the same individual plant, but with new stems and leaves, there must be some sort of provision for the maintenance of its life during the intervening months In other words, it must have had some method of storing up sufficient food to keep itself alive. This material is the surplus organic foodstuffs made by the plant, and deposited in one or other structure or part of itself where it can be utilized at some future time. If the plant be an annual, this reserve food is stored up in the seeds alone, where, as we have seen, it is utilized by the next generation in the process of germinating. In the case of wheat and other cereal plants, the seed becomes filled with this reserve store of food, termed the "endosperm". In many other annuals, as in the case of the pea and the bean, the storage is looked after by the cotyledons.

To a certain extent the same thing happens in the case of biennials and perennials; that is to say, in plants of these types there is also a certain amount of reserve surplus food stored up in seeds. But a biennial plant, and also a perennial one, does more than this, because before it comes to the end of the growth of a spring and summer, it has collected and stored away a considerable amount of organic material in different parts of its structure. It is upon this surplus store



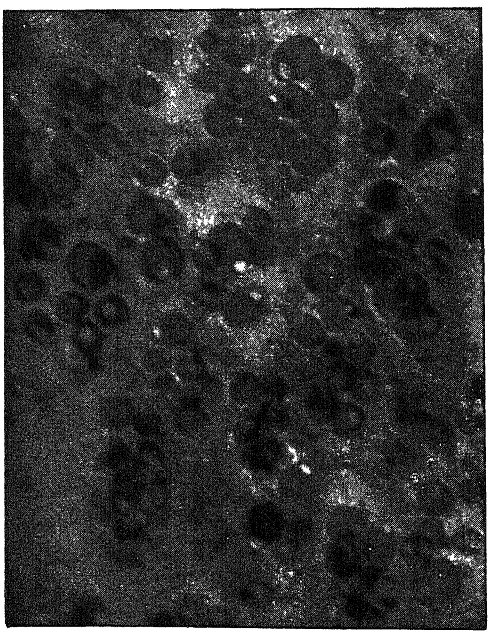
BEAN PLANT AFTER GROWTH OF ROOT AND DEVELOPMENT OF TRUE LEAVES

of food the plant calls for its nourishment in the first part of the following spring, when life and growth become once more obvious to the eye of the least observant.

Other familiar plants offer many examples of various devices for the storage of food. One very common arrangement is to be found in certain roots, such as those of turnips and carrots, where the roots contain the surplus food. We have seen that the onion and similar plants, such as tulips, etc., keep a store of food in

the thick bulb scales. A still more familiar example is the tuberous root of the potato. In hops the storage is in the peculiar roots of the plant, while in most of our trees and shrubs the reserve food is stored during the winter in the cells of the stem itself.

The next question is What are the actual substances or materials thus stored away as reserve food? They are different organic compounds built up by the activity of the cell protoplasm of the plant, particularly a group of compounds which we know as proteids Green plants,



PROTEIDS WITHIN THE SEED

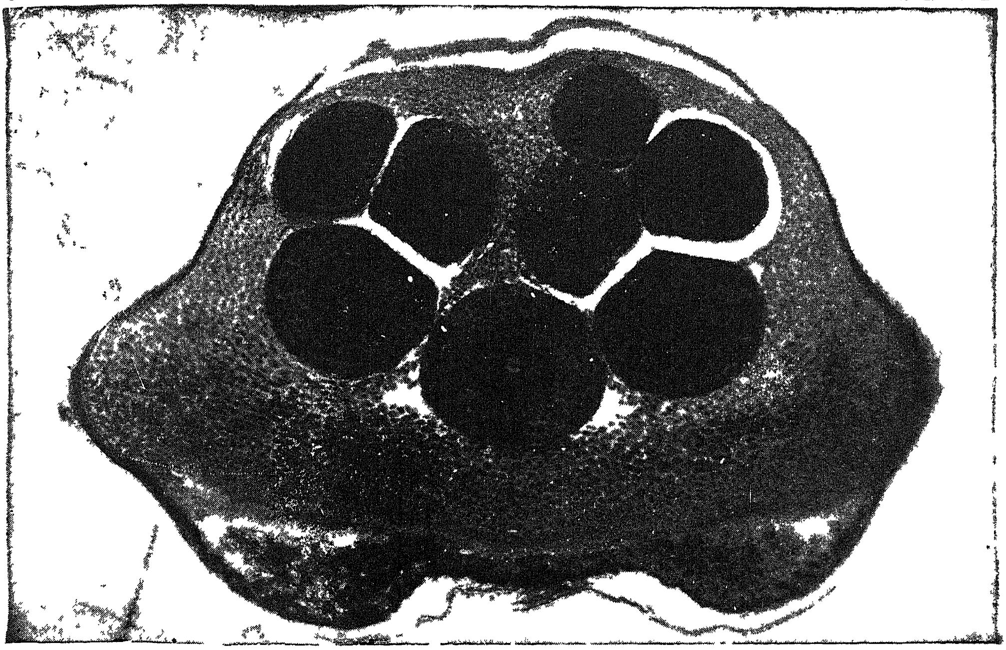
These cells from the endosperm of the castor-oil seed contain aleurone grains, which are proteid crystals combined with an inorganic body termed "globoid" They are here magnified 200,000 times.

while they are growing, build up sugars and other carbohydrates, the nitrogen required for the production of these substances coming from either the atmosphere or the salts in the soil. Some of these sugars and fats are consumed in the early stages of the growth of seeds and bulbs; most of the sugars, fats, and proteids which the plant makes for itself, are used to build up its own protoplasm, and its own cell-walls at the parts where the plant is growing. But if the environment of the plant be satisfactory, and such that active growth is taking place, there is more organic material produced than the plant itself needs for its own immediate use, and this it is which is stored up in the different ways we have mentioned. In most plants these reserves of food are in an insoluble condition, simply because they would require too much space were they to be stored in solution.

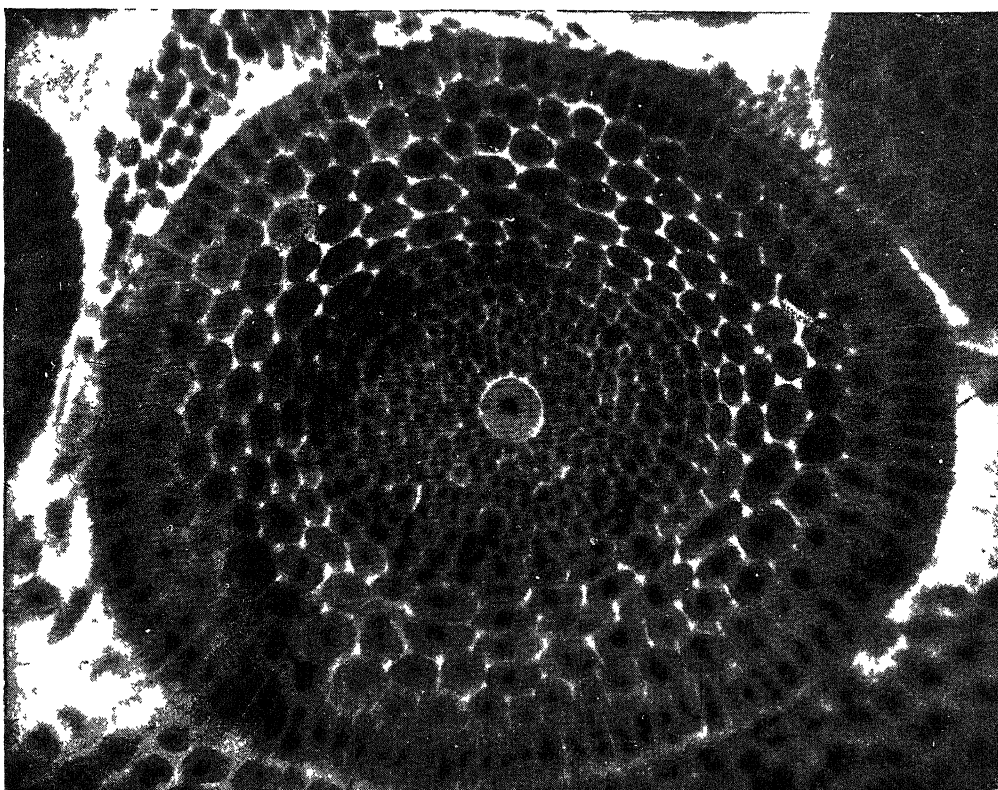
Of all these reserve foods, starch is one of the commonest. It consists of very small grains, made of several layers of the same substance, arranged round a definite point. This starch is in great abundance in roots and tubers, as well as seeds, and it forms no less than from 50 to 70 per cent of cereal grains, while in the case of potatoes from 10 to 30 per cent of the total bulk is composed of starch The granules of starch are not always of the same kind, and some of them are quite distinctive of the species of plant from which they have come.

Other substances stored for reserve are in the nature of oils and fats, such as are found especially in seeds of cotton and flax. In fact, many seeds are the source of commercial oils. An important point to note in this connection is that the substances stored in their final form are not the same as those originally taken up by the plant. Very complicated chemical processes have taken place in the interval before storage could occur, and particularly in the direction of the solubility and the concentration of those materials. In this final form they cannot escape from the cells which contain them, by the process of osmosis; and this is evidently what has been aimed at. It therefore follows that before they can be utilized by the portions of the plant that require them, they must once more be changed into some soluble form of food which can be carried about in the plant by the usual food channels. This is probably chiefly accomplished as the result of the action of ferments, or enzymes, produced by the protoplasm itself. These ferments are very remarkable substances, particularly in this respect — that they can digest, or transform, an almost unlimited amount of the storage food without themselves becoming used up in the process. One of them, which is termed "diastase", has the

THE INNER WORLD OF A BARLEY SEED



SECTION THROUGH THE RADICLE END OF A SEED OF BARLEY 12 HOURS AFTER GERMINATION



SECTION THROUGH THE PRIMARY ROOT OF BARLEY 12 HOURS AFTER GERMINATION

The upper photograph, magnified some 2500 times, shows the disposition of the cells in the primary or largest root and in the secondary roots. The lower photograph represents the primary root under still higher magnification. The nucleus can be seen in each cell.

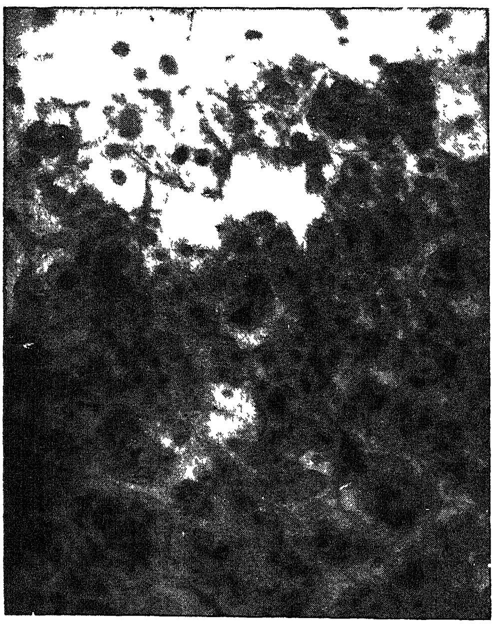
power of transforming insoluble carbohydrates into sugars. This ferment acts upon starch, for example, in seeds which are germinating, and is especially prominent in the seeds of cereals. Another form of the same ferment is found in the leaves and shoots of plants; and by means of its action the starch which has been manufactured by the green parts of the plant during the daytime is actually transformed into sugar during the night This same ferment is abundant in the regions of the eyes of potatoes. Here the starch, which is plentiful, is again transformed into sugar that can be readily carried to the area of growth.

Another ferment which digests these reserve materials in plants is named "cytase", and this is formed in the cotyledons of some seeds, such as peas. Its function appears to be slightly different from that of diastase, inasmuch as it dissolves the cell-walls, wherein the starch is contained, and thus allows diastase to act upon the starch itself.

In some of our common roots much of the organic food material constructed by the leaves in the first growing year is stored up in the root in the form of cane sugar. The carrot is an example of this. The beet is another. Here the reserve is available for use in the following season, but before it can be used it must be acted upon by another ferment which splits up the cane sugar into more readily assimilated forms.

We have mentioned the presence of oil in considerable quantities in seeds such as flax, castor oil, cotton, etc. The ferment that acts upon this form of reserve food, decomposing it, is termed "lipase".

These examples will be sufficient to illustrate the process by which plants keep a store of food available either for their own seeds or for individual subsequent needs. There are other complicated processes, and still other ferments concerned, but the principle in all these cases is the same.



STARCH GRAINS WITHIN THE CELLS OF THE POTATO TUBER AND ORCHID ROOT
The photograph on the left is magnified some 2000 times, and that on the right some 30,000 times

Many of the best examples of the storage of extra nourishment in plants are to be found in some of our most common biennials, such as the parsnip, the carrot, the beet and the turnip, all of these being plants that do not produce seed in their first season's growth, but do so in the second. The immense amount of food stored in these plants gives rise to the fleshy

roots which are their characteristic, and at the same time gives them their commercial value. Some others, with similar roots, exhibit the same phenomenon on a very much larger scale. One plant (*Ipomœa jalapa*) grown in the United States, a relative of the sweet potato, produces storage organs in the shape of roots that may weigh as much as forty or fifty pounds. Sugar and starch are the main food thus stored. Beet roots contain sufficient sugar to produce a large part of the supply of that article of food for Europe. These biennial plants obviously spend the first year of their lives in accumulating this store of food, to be used later. The stem of the second year, which grows very quickly, depends upon this store for its nourishment; and if the root, so large to begin with, be examined at the end of the second year of growth, when the flowers and the seed have been produced, it will be found very much shrunken and withered, because the food stored up in it has been utilized.

Perennial plants, also, have similar storage organs, excellent examples of which are seen in the common rhubarb and the sweet potato. A number of these plants die down completely above the surface of the ground on the approach of winter, but make abundant growth at the first approach of spring, thanks to their fleshy roots and the food within them.

But it is not only in roots, using that term in its proper sense, that this storage takes place, for we find many plants doing the same thing for the same purpose by means of their underground *stems*. These can be distinguished from roots by, among other things, the presence upon them of small scales, that are really in the nature of leaves. Perhaps the best example of an underground stem of this kind, developed for this purpose, is the common potato, which develops the short, thick, underground stem called the "tuber". A careful examination of the whole of a potato plant will show at once that what we call the potatoes — in other words, the tubers — are not developed on the true roots at all, but are attached to branches of the stem that happen to lie underground. What are known as the "eyes" of the potato are rudimentary buds.

Other examples of underground stems are to be found in many bulbs, some of which have thick scales, like the lily. We have said that most of this storage is for the purpose of carrying these plants over the winter season. But it should be added that that remark applies to our own climatic conditions. In other parts of the world, where there is what is termed the "dry season", as opposed to the "rainy season", the storage of food is required to carry the plant over the dry season, and to enable it to grow more rapidly during the wet season.

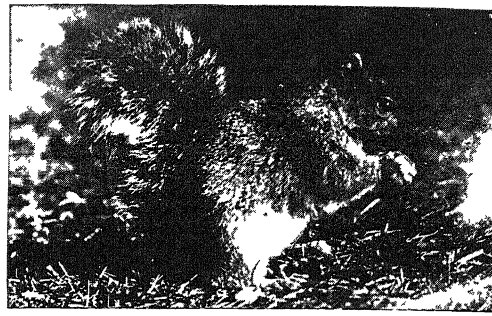
LONGITUDINAL SECTION THROUGH A LILY, SHOWING THE BULB SCALES

Perhaps the most extraordinary case, from some points of view, of the phenomenon of food storage in plants is to be found in the sago palm. Here the surplus food is accumulated in the trunk; and in this plant as much as eight hundred pounds in weight of food material in the form of starch may be accumulated. The outer rind of the stem of the palm consists of hard, dense wood, about two inches thick, and inside is an enormous mass of spongy pith which is extracted after the tree is cut down at the age of about fifteen years. This pith, after preparation, becomes the sago used in the household.

We see, therefore, that starch is a common form of food to be stored, not merely in seeds and in roots, as has been already mentioned, but also in the stems of plants.

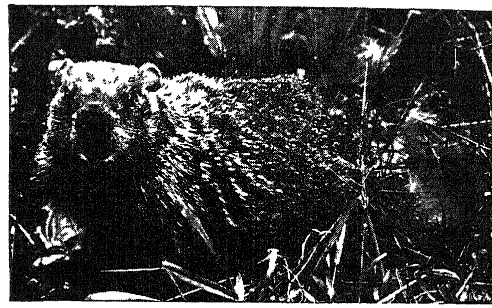
SOME COMMON AMERICAN RODENTS

RED SQUIRREL

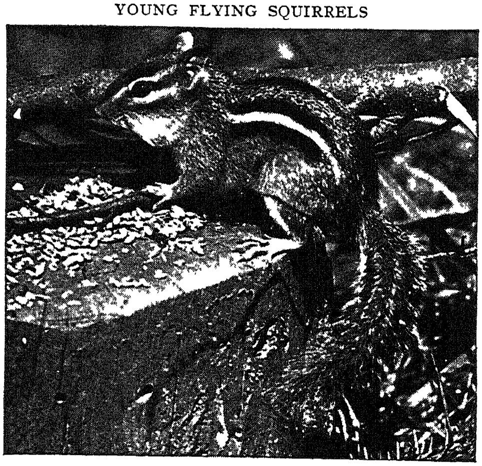


GRAY SQUIRREL

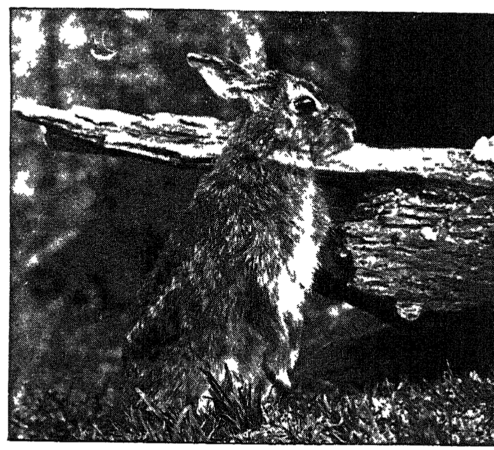
YOUNG FLYING SQUIRRELS



WOODCHUCK



CHIPMUNK



THE COMMON EASTERN COTTONTAIL

SPERMOPHILES

On the left *Citellus douglassii*, on the right California ground squirrel (*Citellus bercheyi*).

YOUNG VARYING HARE OR "SNOWSHOE RABBIT"

Note large hind foot, shaggy fur and white margin to ears — differing from the cottontail.

Photos A. A. Allen, except spermophiles, supplied by the Bureau of Biological Survey of the U. S. Department of Agriculture.

THE GNAWING ANIMALS

A Vast Order of Prolific Mammals with Which Man is Compelled to be Constantly at War

THE PROBLEM OF ANIMAL DESTRUCTION

THE rodents, or gnawing animals bring us to the most widely distributed of all the mammalian orders. Embracing close to two thousand species, many of them almost incredibly prolific, the rodents constitute, by sheer weight of numbers, man's most formidable mammalian competitors. A glance at the life of the rodent world fills with despair those who would hope for a fulfilment of the pledge that the lion shall lie down with the lamb. Only by the constant making of war by carnivorous birds and animals upon the rodents, by the unwaning stress of the struggle for existence in which the weakest and less adaptive are mercilessly obliterated, only through the recurrence of those silent, far-reaching tragedies in nature whereby these animals are swept in unnumbered millions to swift destruction, can man maintain his place in life. The inexorable cruelty of nature's laws is, in the last resort, man's paramount defense against these creatures.

It is a strange and grim cycle of alternating prosperity and adversity that maintains the balance of the rodent world. We have among these animals highly organized creatures, far advanced in the scale of evolution — a tiny harvest-mouse is infinitely ahead of the giant kangaroo in this scale — multiplying in favorable seasons like the grain of the skilful husbandman. That increase brings inevitable disaster. Starvation and disease impel a vast migration — to certain death. If the course were varied, if this cruel annihilation did not follow, the rodents would overrun the earth, and leave man starving in a land barren of vegetation.

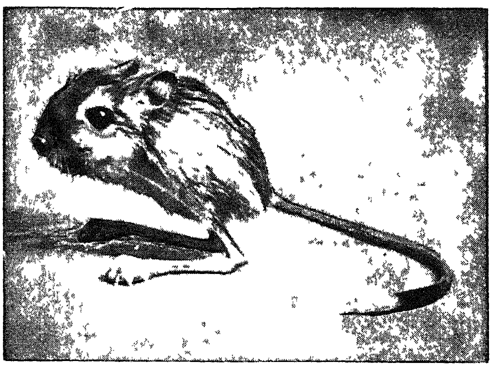
Consider for a moment the rabbit, the chief pest of Australasia, owing to the introduction of a few couples by one of the early colonists. It has been shown that a pair of Australian rabbits will produce six litters a year, the litter averaging five individuals. As the offspring themselves are sexually mature at the end of six months, this one pair, if none died, might be responsible in five years for a progeny of over 20 million rabbits. The ratio of increase with the rat and the mouse is even more alarming. With all our viruses, our traps, our dogs and cats, it is computed that rats cost the United States alone some $189,000,000 a year. The animal is useless where even the most primitive sanitary science is practised; it is a robber; it is a conveyer of disease; it flourishes in spite of man.

The immense area over which the rodents are spread is a convincing answer to those who still affect to believe that each species originated in the surroundings best fitted for its habitation. Rodents are like weeds: they display extraordinary fertility and persistence in a new land. That is not peculiar to these animals, of course. The red deer of New Zealand have far outgrown the size of the Scottish stock whence they were derived; the domesticated reindeer imported into Labrador rival in size the giant wild reindeer of Siberia; the foxes, carried in an evil hour by a Cumbrian sportsman, for the sake of a hunt or two, to Australia, have become infinitely larger and more powerful and destructive than the original English stock. But the multiplication of rodents in new areas eclipses all other examples of the kind.

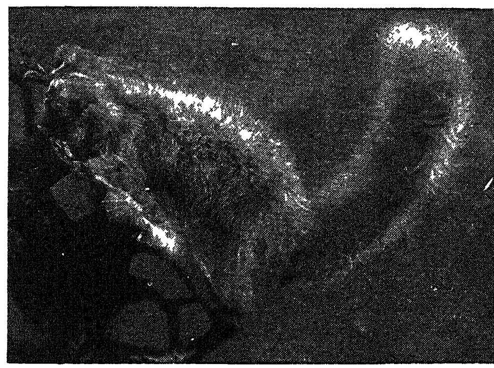
The gnawing mammals are an instance of nature's ability to ring the changes upon one design. Certain peculiarities of the rodent's molar teeth recall the dentition of the extinct mastodon, while a peculiarity of the guinea-pig has its parallel in the molar tooth of the modern elephant. The incisors of the rodent are suggested by those of the curious aye-aye, which belongs to the lemur group. These incisors are the paramount feature of interest in the dental equipment of the rodent. With these front teeth it gnaws. It has two in the lower jaw and two in the upper, except in the cases of the hare and rabbit, which are distinguished by the presence of four incisors in the upper jaw.

Another peculiarity of the rodent mouth is that it is departmentalized. The fur of the face is continued into the mouth, which it divides into two distinct sections The purpose of this is to guard the animal from the danger of getting into its throat any foreign substance which it may be gnawing. The entire mouth of the rodent, both as to this particular and as to the teeth and the specialized shape of the jaw, which admits of the peculiar movement necessary to the mastication of the animal's food, is a beautiful example of adaptation.

The great majority of the rodents have five toes to each foot; and though there is not a thumb or an opposable great toe in



AN ARABIAN JERBOA: THE KANGAROO OF THE RODENTS



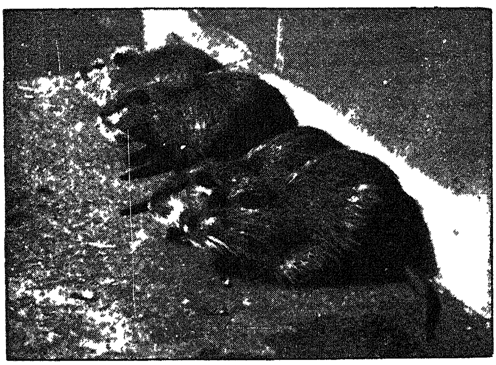
JAPANESE FLYING-SQUIRREL WITH PARACHUTE

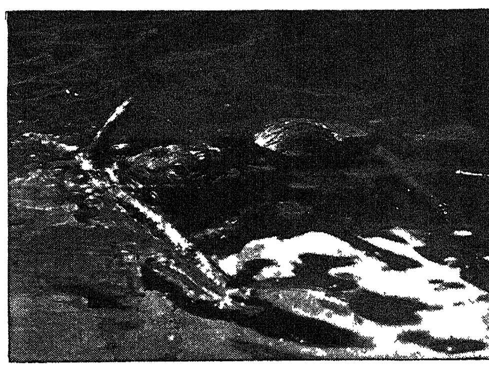
the whole order, the extreme mobility of the forepaws of the beaver, the rat, mouse, squirrel and other animals, strikingly suggests that a rat or a beaver if he had the good fortune to have been blessed with thumbs must have gone very far in the mammalian scale.

A rodent's incisor is one of the finest tools in nature. It is a natural chisel, provided on the outer surface with a hard enamel, and on the inner surface with bone which is comparatively soft. As the tooth is used, the inner, softer side readily wears away, always maintaining the sharp edge which the enamel imparts, so exposing a fine cutting surface. The whole tooth grows continuously throughout the animal's life, at a rate commensurate with use, so the rodent, be it beaver or porcupine, hare or mouse, has ever a perfect equipment of tools in its mouth. The chisel is modeled, probably unconsciously, upon the rodent's tooth, with soft iron on one side and hard steel on the other. The ax is another cutting tool of the same derivation — a double chisel, with steel in the middle of the blade and two sections of softer metal, one on each side.

We shall have to content ourselves in this chapter with glances at some of the more notable rodents. We shall reach the rats, mice, voles and porcupines in later chapters, while important members of the order have been discussed in a preceding one. We have to note by way of further preface that homes are fashioned by these animals in nearly every available medium. They burrow, they build, they nest, they swim, they even fly. We find the flying animals among the squirrels, which constitute the first family of the order.

The flying-squirrels are more common than is generally supposed. They occur in practically all the Oriental countries, in North America, in northeastern Europe and Asia, in Siberia, in India, in the Malayan countries, and so forth. Of course, the so-called "flying" is only parachuting, performed by means of a fur-covered membrane attached to the fore and hind limbs on each side. In the bat, the hand has become the wing, with the fingers as the supporting rods of the structure. In the flying-squirrels, however, the toes are all free. In all but an African group the parachute is supported by a rod of cartilage produced from the wrist, while the membrane bridges the gap between the hind limbs and the root of the tail, a similar extension joining the forelegs with the neck.





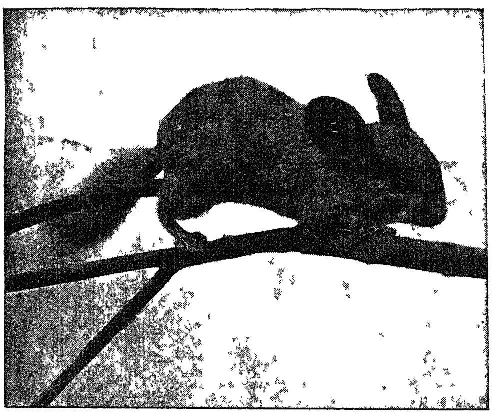
THE SHOWMAN'S "GIANT RAT": A LARGE AQUATIC RODENT, THE COYPU, ON LAND AND IN WATER

In the scale-tailed squirrels, a family composing two distinct genera, and confined to Africa south of the Sahara, we have a squirrel with a parachute of slightly different design. Here the skin is supported by a rod emerging from the elbow instead of from the wrist. Another peculiarity of this squirrel exists in the fact that, extending for some little distance from the root of the tail, the under side of that organ is armed with scales, which afford the animal considerable assistance in climbing.

Whatever their other characteristics, all these flying-squirrels have much the same method of performing their aërial journeys. They cannot fly upward from the ground, nor from a lower to a higher branch. The flight must begin in a downward direction. The impetus gained by this volplane affords the little animal power to rise slightly in the air after the preliminary descent, and also to some extent to change its course when in mid-flight. The distance covered varies with the size of the animal, from the 90 feet and upward of the lesser flying-squirrels, to from 150 to 250 which the greater may achieve.

North America abounds in arboreal as well as ground-keeping squirrels, and they are divisible into many species. Those most common in the eastern half of the country are the red squirrel and the gray squirrel. The former is the smaller and more active — an excitable little rascal which scolds at you as you enter his woodland haunt, or chatters saucily from the orchard fence. His color is rust-red above and white from throat to belly, with a dark stripe along the side. His house is usually a den beneath the roots of some old stump, or in some hollow tree. Here the family dwell in winter, but only the severest weather keeps them shut up. Their stores of nuts, acorns, etc., are laid away in various adjacent nooks and corners, but are seldom buried. The red squirrel, in another of its numerous varieties, inhabits the whole continent except its arctic border and the open plains. In the Rocky Mountain region is found Fremont's squirrel, which is yellow-gray, with a dorsal as well as dark lateral stripes; and on the Pacific Coast lives Douglas's squirrel, whose upper parts are dark gray, with dark dorsal and side stripes, and the lower surface yellow to deep orange. They inhabit the woods and have much the same active and loquacious temperaments and habits as the eastern red squirrels.

The gray squirrel inhabits the eastern half of the United States and Canada, and is decidedly larger than the red one. It is mouse-gray, often showing a yellowish tinge, and has a great feather-shaped tail edged with white. It is very numerous, and is semi-domesticated in villages and public parks all over the country. Its food is varied, and includes many insects and grubs, but it seldom robs birds' nests as does its red brother. It inhabits hollows in trees, or little houses placed there for its accommodation, and often constructs great nests of leaves among the branches of tall trees. In such places it stores food for the winter, and it also buries great numbers of nuts and acorns; but it is abroad all winter, and makes little use of its savings except in the snowy north. In some parts of the country it is regularly shot for the table in the autumn. In the Mississippi Valley and in the Southern States are to be found two somewhat larger squirrels called "fox squirrels" because of the fox-colored tint of their coats. Their habits are similar to those of the northern gray species. All these squirrels develop jet-black races, but there is no proper "black" species. Abert's squirrel and other related species belong to the southwestern border; and Mexico has one or more orange-and-black squirrels of great beauty.


A TREASURED FUR-BEARER. THE CHINCHILLA

The American flying-squirrels are of two kinds — the common one of the eastern woods, and a much larger and darker form that dwells in Canada and in the western mountain region.

At the other extreme in the squirrel family are the ground-loving prairie dogs and chipmunks, mentioned in the chapter on Animal Home Builders; the numerous species of spermophiles or ground squirrels of western North America; and the large, clumsy woodchucks or marmots which one would scarcely think of calling "squirrels" unless he were familiar with their anatomy. Most of these ground squirrels become serious pests wherever abundant about gardens or grain fields, and it often proves necessary to poison them on a large scale. The U. S. Biological Survey, coöperating with some of the Western States, has succeeded in almost exterminating some of the worst species over large areas.

Those of us who are familiar with its engaging manners desire to see the graceful little red squirrel thrive abundantly in our woods, but old legend and suspicion have been verified. In the summer many squirrels may ruin a plantation of young trees by nipping off the tender shoots; and they are rapacious robbers of birds' nests, taking not only the eggs, as has been so long alleged, but actually the callow nestlings. On the other hand, we owe many a noble oak to the acorns hidden in forgotten days by squirrels who meant only to insure a meal against some cold and barren tomorrow.

There are many varieties of squirrels, from the Indian giant, which measures twelve inches from the tip of the nose to the root of the huge, bushy tail, or the huge, woolly flying-squirrel, which is six inches longer, down to the pygmy squirrel, with a body-length of barely more than three inches. Then we get right away from the family to find a relative of a far distant date in the sewellel, which today has not a near relative in the world, and is restricted to the high mountains of eastern Oregon and Washington. It is an animal a foot in length, but with only an inch stump of tail, and it carries a head resembling that of a pug dog. A living relic of a dim past, dwelling in moist ground, and feeding upon plants in the streams near home, it can, by means of its tight-gripping paws, climb the lower branches of trees.

We come next to the jerboas, the kangaroos of the rodent family. Such characterization refers, of course, only to the extraordinarily lengthened hind legs and to the flying leaps with which, when at speed, they progress over the ground. The kangaroo always hops, but the jerboa when moving slowly crawls inelegantly upon all fours, resembling rather the frog or the toad which, when advancing upon its prey or when overcome with fear, waddles upon all four feet. The jerboas are characteristic of the deserts of the Old World, and especially of Africa and southwest Asia. Their diet is, strictly speaking, vegetarian, but some species will eat eggs and even birds; while one, the Afghan species, has mastered the secret of almost complete abstention from water when in a state of freedom, though accepting liquid when captive. Jerboas kept as pets are docile and affectionate, but to confine desert animals fashioned for such boundless freedom seems rather like cooping up some wandering Arab from the tented wild within the limits of a city apartment.

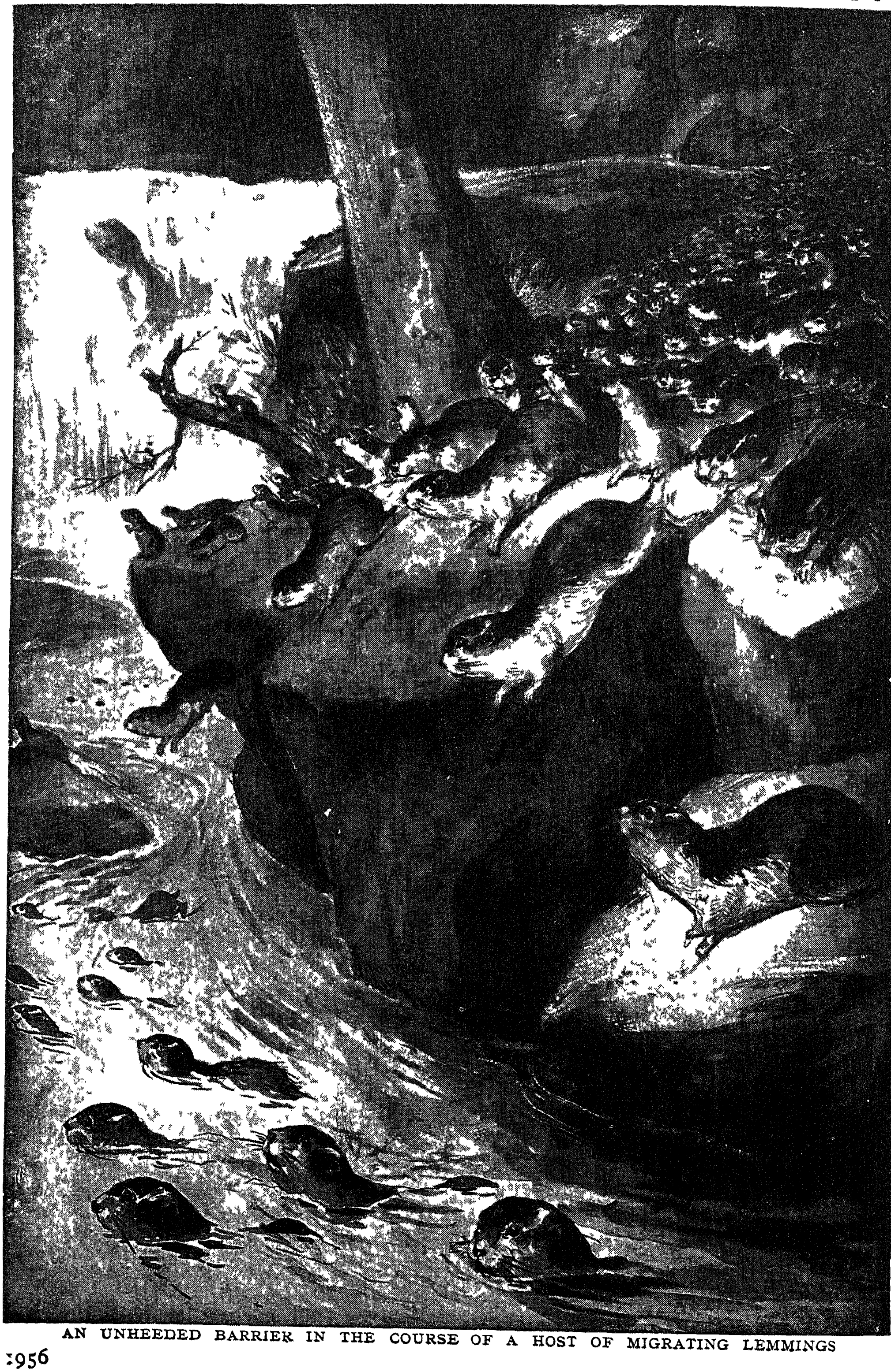
When we come, in a later chapter, to the jumping mice and rats, we shall see how the jerboa-like design has been utilized a second time. Here, however, we pass to the lemming, which is a close ally of the short-tailed field-mouse, found in Scandinavia, in northern Asia and North America. Lemmings resemble the field-mice in appearance and mode of life, dwelling in burrows, but feeding upon grass, reindeer moss, the catkins of the birch and various roots. The chief interest in these animals is, however, associated with the manner of their death, when fate sweeps them in multitudes to destruction. It may be noted in passing that Siberian squirrels are impelled periodically to migrations from which none returns, but the lemming's is the most frequently cited example of the crusade that knows no coming back.

The march is like that of the springboks many times multiplied, and the origin seems to be the same. It is all a matter of food, but the lemming makes its terrible march not yearly, but only once. It is the penalty it pays for excessive prosperity. A colony is started upon the mountain slopes, and speedily attains considerable dimensions. If the weather be severe and the summer not too long, the number of the animals is kept within reasonable bounds. But should spring come early and a year of special abundance follow, the increase in the lemming colony is almost incredible. Disaster may not follow until the next year, or it may come in a long summer following an early spring. The early arrival of summer accelerates the growth of vegetation and with every prospect favoring, the lemmings become millions. The heat of summer scorches up the vegetation, and the overwhelming host of lemmings finds the stock insufficient. Starvation faces them. They do not set out to new grounds and then turn back, after the manner of the springboks.

A SOUTH AMERICAN RODENT: THE PACA

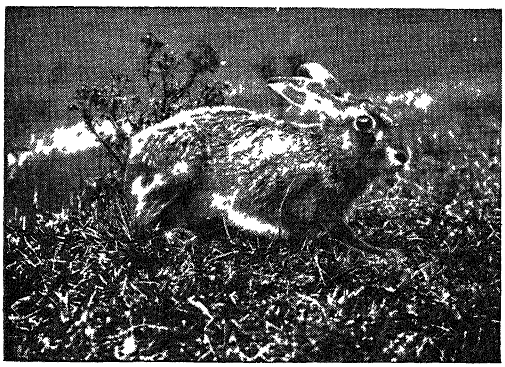
They set out to march to death. The migratory instinct seems to settle upon the lemmings of a vast area all at once. Now, whether all go, or whether some remain laggards, or as guardians of the old home, has not been decided. The lemmings that march out never return; and for two or three years after their departure no lemmings are to be seen in the old quarters. Then a few are observed, and from these a new colony is built up on the old site.

Meanwhile, the army that marches out forms a spectacle of which many men have written with pens dipped in wonder. In innumerable hosts they press forward, millions upon millions of them, all in column, their little feet pressing out a deep path where the myriads pass. All the food encountered by the vastly long column is



AN UNHEEDED BARRIER IN THE COURSE OF A HOST OF MIGRATING LEMMINGS

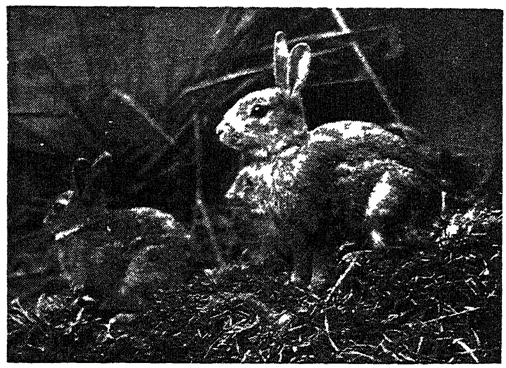
eaten by the vanguard; the others throng despairingly on. They will not look at a stream in ordinary times, but now they swim lakes and rivers, cross fjords and arms of seas; they eat their way through haystacks, they crowd streets of towns and villages, they swarm through houses, they press on over mountains. Nothing stays them so long as life lasts Messengers of death, winged and four-footed, prey upon the stampeding host; waters drown enormous numbers of them; epidemics mow them down as they march. For miles and miles the way is strewn with the bodies of the dead, and the rest struggle on until not a living lemming remains. Such is one of nature's hideous expedients for the reduction of excessive population, and none ever devised could be more effectively complete.



THE GREYHOUND OF RODENTS THE HARE

We find an analogous case in the fate of the snowshoe hare (*Lepus americanus*). This animal enjoys cycles of great prosperity — seven fat years in which its numbers are enormously increased It becomes the staple food of all the North American carnivora, from man to glutton. The Indian, during the year of the snowshoe hare's abundance, forbears to track larger game. Why should he trouble when his squaw can go into the woods and knock on the head as many of these animals as are required to fill her cooking-pot? The flesh-eating animals, too, find food so easy to obtain that wolves and other preying animals leave the larger game comparatively in peace. The larger herbivores, therefore, enjoy a time of rest while the prolific hare is multiplying and filling the mouths of the hungry. And then, after the seventh year, when the wilds are alive with these hares, "the animated wheat of the woodlands", as they are called, come plague and pestilence, and their numbers are reduced almost to vanishing point. The disease passes; the animal is too scarce to make its pursuit profitable; men and animals turn to more considerable game, and the hare is left in peace and health, to increase once more until again he attains numerical proportions sufficient to become the stockpot filler and food of the carnivores.

Take again the strange case of the coypu, a large aquatic rodent, called by showmen "the giant rat", but more nearly resembling the beaver in certain characteristics. The Spaniards regarded it as a species of otter, and called it the *nutria* — which is



THE BANE OF AUSTRALIA WILD RABBITS

Spanish for otter It is by that name that the fur of this animal is known, but it is commonly sold as beaver There was a great demand for this fur some time ago and the coypu, whose range is limited to the rivers and lakes of South America, became very scarce. A decree was therefore published forbidding their destruction. The consequence was that the coypu changed their habits. Naturally, they burrow into banks and feed upon water weeds, but now, no longer menaced by man, they took to the land, displayed a migratory instinct, and swarmed everywhere in search of food. Thus habit and diet were altered, and the animals throve extremely upon the change. Suddenly a mysterious malady fell upon them, from which they perished and became almost extinct.

Among the most valuable of the fur-bearing rodents are the chinchillas, little burrowing animals distinguished by the kangaroo-like length of their hind limbs, and restricted to the mountainous districts of South America and to the West Indies. The common chinchilla, which supplies the exquisitely soft fur of commerce, has five toes on the fore feet and four on the hind feet, and carries a long, bushy tail; but in the same genus is the short-tailed chinchilla, an animal of greater bodily bulk than the other, and also differentiated in the respect which its name implies. The largest of the chinchillas is Cuvier's, the fur of which, however, though much sought, is far less valuable than that of the true chinchilla.

THE PATAGONIAN CAVY, OR MARA

An interesting group of South American animals follows, beginning with the agouti and the paca. They both resemble extremely large guinea-pigs, the agouti measuring from eighteen to twenty inches from nose to tail, and the paca reaching quite two feet in length. Both are hunted for food, their flesh being considered a delicacy, a particular in which they are distinguished from the cavies. The latter are divided into four species, although the many breeds which have been evolved from the domesticated animal would suggest to the fancier that there must have been infinite natural resources upon which to draw to obtain such varied results. But all our tame varieties are now shown to have descended from one species, Cutler's cavy, which was first domesticated by the Incas in Peru, whence it was carried to Colombia and Ecuador, and brought to Europe soon after the discovery of America. In a state of freedom, cavies frequent marshy districts, where they are sheltered by vegetation, or sandy areas, in which they can burrow. There is one species, however, the Bolivian, which is confined entirely to the higher regions of the Bolivian Andes, where it may be found in large colonies at an elevation of from ten thousand to sixteen thousand feet.

The guinea-pig, like the ferret, prospers more in confinement than when at liberty, both animals proving much more prolific when kept as pets than when dependent for food supply and shelter upon natural conditions. There is one cavy of which the average breeder knows nothing. That is the mara, or Patagonian cavy, a large rodent which at first sight might be mistaken for a member of the hare family or even for a small deer. It attains a length of from two and a half feet to nearly three feet, and stands over a foot in height at the shoulder. The largest of all the rodents is the carpincho, or capybara (also spelled "capivara"). It is a native of all South American rivers on the east side from Colombia to La Plata, and, with a length of about four feet, may weigh nearly 100 pounds. It is a pig-like animal, and is locally known as the "river-hog", but the superior length of its hind limbs causes it when pressed not to run or gallop, but to spring or leap. Although the carpincho damages the bark of young trees, it must have played an important part in keeping watercourses clear, for it feeds chiefly, when not tempted into larceny by cultivated crops, upon aquatic growths which, left to riot unchecked, might eventually choke a river and cause the flooding of the land around.

The picas, hares and rabbits bring us to the end of our list. The picas are small, tailless animals, and the nearest allies of the other animals named, inhabiting northern and central Asia, part of eastern Europe and North America.

GNAWING ANIMALS THAT AID MAN

U S Civil Service Commission

This technician is testing the effect of a medicinal preparation on a guinea pig. Guinea pigs are frequently used for experimental purposes.

Commercial Solvents Corp.

Trying out the effectiveness of a penicillin preparation on a group of rabbits Experiments like these have brought about many great advances.

Borden Company

The cages shown here house white rats, on which different food combinations are being tried out.

They form huge underground colonies, and the Mongolian specimen, at all events, has the ability to dispense entirely with liquid during the recurrent annual period of drought. Most of the picas frequent the higher mountain ranges; some in the Himalayas flourish at an elevation of as much as 19,000 feet above sea level. The hares and rabbits have the lower levels to themselves, though we have mountain hares as well as polar hares and wood hares and marsh hares and many another species differing in size and color as in habitat.

Hares and rabbits form one genus, but there is much difference between the characteristics and habits of the two. The hare is born clad with hair and with its eyes open; the rabbit at birth is naked and helpless. The common hare has its home absolutely in the open; the rabbit makes such burrows as to become a public danger, even undermining highways.

Much as we read of this plague of rabbits in Australia, none of us can realize what it means — the miles upon miles of pasture ruined by these teeming rodents, the thousands of square miles of land inclosed by "rabbit-proof" wire netting, and the farmers driven to despair as their plans for the extermination of the furry locusts are defeated.

These remarks apply, however, to the European representatives of the species. Properly speaking, America has no rabbits, except in captivity, including the so-called "Belgian hare", which is only a big breed of European rabbit. Our "rabbits"— for the name is too commonly used to be neglected — are really hares, and consist of several species. The common little wood-rabbit or cottontail of the Eastern States remains numerous everywhere, and affords much sport to rural gunners. In so far as its young are born blind and naked, it is a rabbit, but though it often takes refuge in holes in the ground, it never digs them itself. Nor does it have its young in burrows like the true rabbits, but in "forms", usually in thick grass like the hares. The mother cottontail pulls fur from her own body with which to cover the young whenever she leaves them to go on a foraging expedition. In northern New England it is replaced by the larger "varying hare" This animal is extremely numerous all over Canada, and forms the principal reliance for food of the lynx, pekan and other fur-bearing animals, and of the native population of the region. It is the species referred to in this chapter as having alternating periods of scarcity and abundance. In summer it is brown, but when the snowfall begins, it turns white and remains so until spring, when it sheds the white hair and gets a brown coat. On the Arctic coast and islands is found the large polar hare that is white all the year around. Various other species have a more local habitat as, for instance, the bright brown little swamp-rabbit of the Southern States.

The open prairies and plains west of the Mississippi River, and the treeless valleys and basins south and west of the Rocky Mountains and in southern California, possess several species of large hares that are called "jack-rabbits" because of their great, donkey-like ears. These ears are their principal means of guarding against a dangerous surprise by some rapacious enemy, and they are erected on the slightest alarm. Their hind legs are long and strong, and carry the animals away in a series of long leaps with amazing speed. As they find an abundance of grass and herbage for food accessible in winter as well as in summer, they remain abroad at all seasons, making simply a "form" under the shelter of a bush, and sleeping impervious to cold in the thick fur of their coats. This is true, in fact, of all the American rabbits.

The western jack-rabbits have increased greatly in certain districts, and especially in California, as the partial settlement of the country has killed off the coyotes, badgers, hawks and other natural enemies that formerly sufficed to keep their numbers within bounds. It has been necessary in some places, therefore, to organize great "drives" of these rabbits and, after concentrating them in a corral, to kill them by thousands. This reminds one of the vast damage done in Australia by the amazingly rapid spread of European rabbits there.

MAN'S COMPLEX NERVES

The Nervous System in Man and Beast, and the Nature of the Difference Between the Two

MAN'S INFINITE CHOICE IN ACTION

WE have now dealt in succession with the various "systems" which comprise the body of man, and have stated the essential relation between the nervous system, the last to be reached, and all the others — that they are for it and not it for them. When all qualifications have been made, that remains true. The body is a nervous system, evolved and imposed upon circulatory, digestive, respiratory, glandular, bony and other systems. Taken as a whole, the function of all these is to repair, protect, cleanse and ventilate the nervous system, to make it as nearly as possible independent of external circumstances, not at their mercy, though none the less aware of and able to deal with them. But these other systems have another most important function, which is to store up energy for the use of the nervous system. A very great part of the weight and bulk of the body is made of muscles, which are the end organs of motor-nerves, and which contain extraordinary quantities, very easily replenishable, of energy in the form of sugar and allied chemical substances.

Thus the essential reason why the body of man is so complex — all the preceding chapters taken together merely outline the main principles of it — is that the nervous system desires and requires to be as complex as we find it to be. This unimaginable complexity of the nervous system is the supreme fact of the anatomy of man, because of what it makes possible for his conduct, internal and external. It indispensably serves the deeds and the thoughts of man, which are man essentially, nor could any simpler structure serve him thus so well, as we shall see.

But the more complex the nervous system, the more withdrawn from the outside world, and yet the more closely and subtly related and responsive to it, the more does it need by way of support and ventilation and chemical and mechanical appliances and apparatus. Hence the complexity of the body, the amazing number of specialized cells and organs which have been added to it in the course of its development. Each of these new parts is itself alive, and has its own requirements. It reacts on other parts, and they react on it, so that there is no end to the complexity, and yet with all this there remains a no less wonderful simplicity of meaning. For the body, with all its details, exists for the purposes of the life of man, which consists of some kind of action. Let us look at the nervous system afresh from this point of view.

Or, rather, let us first understand what action involves, and how it evolves, in the history of that branch of life of which man is the highest and growing point. And as we trace action, conduct, response, in broad outline, we shall observe how the nervous system appears and evolves correspondingly, requiring more and more of the other arrangements we have already described, until at last we see what the body of man is from the standpoint of a true theory of evolution. We trouble here no longer with the nineteenth century view that the body of man is composed by the accumulation of a vast number of chance variations which persisted and stuck together because they were advantageous. We see clearly that the body is crammed with purpose, and if we would interpret it correctly we must realize what that purpose is.

Purpose is a great word. We do not here mean destiny or purpose in the highest sense. It is quite enough that we should recognize, at this stage, the immediate purpose of the body of man, which is *action*. This is, of course, true of the body of any animal; and it is in the comparison between bodies and nervous systems (when they appear) from the lowest animals up to man that we begin to see why man's actions, conduct, behavior so transcendently excel anything that the lower animals display. Action is for life, or life is for action; and it is idle to pretend that there is any fundamental difference in the bases of conduct, whether we observe them in the amœba or in man — in the one-celled animal that has no nervous system, or in the animal whose nervous system alone contains thousands of millions of cells

To move towards food and to swallow it is a kind of action common in all its essentials to amœba and to man. The machinery is very different, but the action, the purpose of the action, and the need of the action are precisely the same. The man, with all his complexity, is thus just as simple as the simple amœba so far.

How man is exceedingly different from and yet similar to the lower animals

Therefore, if we are to understand man and the meaning of his nervous system we must trace action upwards in the history of life, and we must try to keep our heads amid the two temptations to which so many of our predecessors have succumbed. They are quite obvious, but none the less perilous, somehow. One is to insist upon the agreement between man and the lower animals, of which there are so many staggering examples like that already furnished, and to conclude, in short, that the difference between man and the lower animals is largely one of degree; not great even at that, but of kind not at all.

The arguments for this view are many and easy and satisfying, and lead to the humorous conclusion of the French writer Beaumarchais that, in some cases, man differs from the lower animals at least in that he eats when he is not hungry and makes love at any time.

The other temptation, just as commonly succumbed to, is to declare that man is so wholly unique and apart that to introduce any comparison between the springs of his conduct and that of the lower animals is to dishonor him and to know nothing of him. The arguments for this view are just as many and satisfactory as for the other. The only condition, in either case, is that one shall know what one wants to see, and shall look only at the evidence in favor of it. But the real truth is the evolutionary one, which we are now beginning to perceive that man is exceedingly different and exceedingly similar to the lower animals, both in body and in function, which ultimately means behavior

Unlike either of the half-truths above indicated, which respectively dishonor either man or the lower animals, the whole truth honors him without dishonoring them. We may freely recognize in the nervous system of the dog, for instance, a structure which seems suitable for the display of intelligence, and may unreservedly admit the display of intelligence in the conduct of such an animal, without for a moment regarding Beaumarchais' definition of man as anything but a vulgar falsehood.

Similarity between man and the simplest organisms in procuring energy

Let us see, now, whether these large statements can be justified. The body is a machine for action. The action requires energy and apparatus, and so forth, according to the laws of physics, but the object is simple, and it is realized by the very simplest organisms we know. The amœba is aware, and replies. Its life essentially consists of two processes — first, procuring a supply of energy; and, second, spending it as it will. So, also, does the life of man. Let us see how the evolution of a nervous system and, above all, of man's nervous system, affects these two processes. As regards the first, we shall not trouble, being intent to note its essential character for man as for the amœba. The differences that exist between the two in this respect of "getting", matter little; it is the difference in the respect of "spending" that matters everything.

A MICROPHOTOGRAPH OF ONE OF THE MANY SERVANTS OF THE NERVOUS SYSTEM

The nervous system of man is by far the most complex of all his systems; and in this picture of a spinal ganglion, shown in longitudinal section down its center, and magnified fifty times, we see a kind of seat of nutrition for the nerve fibers that pass through it from some portion of the body to the spinal cord. The numerous circular ganglion cells, seen in this picture with their little dark nuclei, send fibers to unite in a T-shaped junction with the fibers passing through the ganglion.

The reflex action of the least developed living thing not wholly mechanical

There is no doubt that, until very recently, men of science have underrated amœba and such humble forms of life. But it is still true that, in the main and essentially, their behavior is *reflex*, as we say, and very little more. It is vastly important for our philosophy that there *is* a little more, but it is only very little. For the rest, the action of the amœba is reflex. And here we meet a phrase, "a reflex", or "a reflex action", which is of enormous importance in the study of all forms of animal life and, above all, in the study of the nervous system. The term is not used as strictly as it should be, and different authors often arouse controversy and misunderstanding in consequence. But we mean by it an action which is so constant and rigid and automatic, to all appearances, that it may almost be called a reflection, like, say, the rebound of a billiard-ball from a cushion. If the cushion has "acted", its action is certainly a "pure reflex", constant and automatic.

Now, we shall do well to rid ourselves from the first of the idea, still held by all but the most profound and advanced students, that any reflex action is wholly and truly mechanical, like the "reflex action" of the cushion of a billiard-table. To call it a reflex is only to use a bold metaphor.

Reflex action always involves the psychical fact of sensation

Life is always involved, as we see at once when death supervenes, or the death of the particular nerve-cells involved, if such there be, or when fatigue or intoxication bv anæsthetics or otherwise abolishes what we call reflex action. The reflex may be extremely simple, it may be invariable, it may look like the response of a machine, but that is only because life is using machinery for its purpose. The climb from reflex action up to that of the human will is not a climb from unconsciousness to consciousness nor from machinery to life. In the humblest and simplest and oldest reflex action or response of life there is always necessarily involved the psychical fact we call *sensation.*

The law stating "No sensation, no reflex", is absolute. The hair of a living animal, or even of a dead animal, will be pulled, and the skin will return when the pulling ceases. That is elastic response, purely mechanical and independent of sensation. The hair of a living or a dead animal will burn when a match is put to it. That is chemical response, equally independent of sensation. But if the animal be alive, and not poisoned, asleep, or otherwise put out of action, it may *feel* in these cases, and may exhibit a reflex, biting in the direction of the pull, running from the match, or what not.

Sensation the very basis of life

You may also stand beside an automobile, touch a lever, and it will run away; and there we see the mechanical imitation of a reflex action, or the mechanical apparatus of a reflex action. But a real reflex action is a vital act, involving sensation.

Sensation lies at the very basis of all life, above all of the life of man. We shall study it is as a whole before we proceed to study the special forms of apparatus which he possesses for special kinds of sensation. Meanwhile we simply assume sensation for the present purpose. We shall rightly talk of reflex action as automatic, as largely mechanical, as rigid, as involuntary and so forth, but all the while we shall be assuming, because we must, the existence of a psychical fact, which is eternally different in order from anything that those adjectives suggest and which is called sensation.

Now, the amœba feels and responds, though it has no special organs of sensation. It need detain us no further. The next stage that needs description simply shows us a special machinery for feeling and replying, which we call nervous. It is not evolved all at once in this form, but we may pass over its rude sketches, and look at the form which we find in all but very humble animals, and which occurs in millions in the nervous system of man. It is called a reflex arc, or a sensory-motor arc. Not long ago distinctions were drawn between the two; the reflex arc was said to serve a reflex act, in which there was supposed to be no sensation, or only an "unconscious sensation".

Sensation occurs accompanying action in the very humblest of organisms

Such a term is an absurdity; for we know that if any supposed reflex arc not needing sensation be treated so that no sensation can occur, no action will occur. That suffices, and we shall not draw a distinction which does not, and could not, exist.

The typical reflex or sensory-motor arc, such as we find in our own bodies, will consist of a sensory half and a motor half, together with any necessary machinery. A sensory nerve will run from the skin or the eye or anywhere else to some central point, from which a motor nerve will run to a muscle (which is merely the end organ of a nerve); and when a stimulus runs to the center along the sensory nerve and a consequent sensation is felt in the nerve-cell of that sensory nerve, an order will be given by the nerve-cell of the motor nerve so that a movement will occur — the eye, threatened by a blow, or needing the moisture of a tear, will wink, or some such simple reflex action will occur. The anatomical details of the machinery do not much concern us. Few or many nerve-cells may be involved. The movement need not be that of a muscle, for it may be movement in the cells of a gland that secretes saliva or tears or what not — as when our mouth "waters" at an appetizing odor. The sensation may be of any kind, the motor response may be of any kind, but still the act is essentially a reflex or sensory-motor act, performed by means of a nervous arc.

Anatomically the nervous system exists to control the body

If we look at the nervous system of man as a whole, we shall find it hard to believe that there is any particular resemblance between so complicated and various an apparatus and anything so simple as the reflex arc. Yet we can historically trace the evolution of the nervous system from the first to the mature stages of the individual man, and satisfy ourselves that this is, essentially, a number of sensory-motor arcs, no more and no less.

We might imaginably replace all the sensory fibers and cells by one, all the motor fibers and cells by one; and we should have everything that is essential in the nervous system. To it we should require to add a variety of machinery for other purposes, but that would not be essential. If we are to have a heart, and lungs, and so forth, these and other organs will require nervous control. Then, of course, anything so complicated as the body will require much controlling machinery if its parts are to act as a whole, If, therefore, we look at the nervous system anatomically and without any clue, we shall think of it as existing in relation to the rest of the body. We shall observe the nerves running to and from all parts, and we shall insist that the nervous system exists to control and coördinate the whole, to supervise the nutrition of the various organs and keep them in touch with one another.

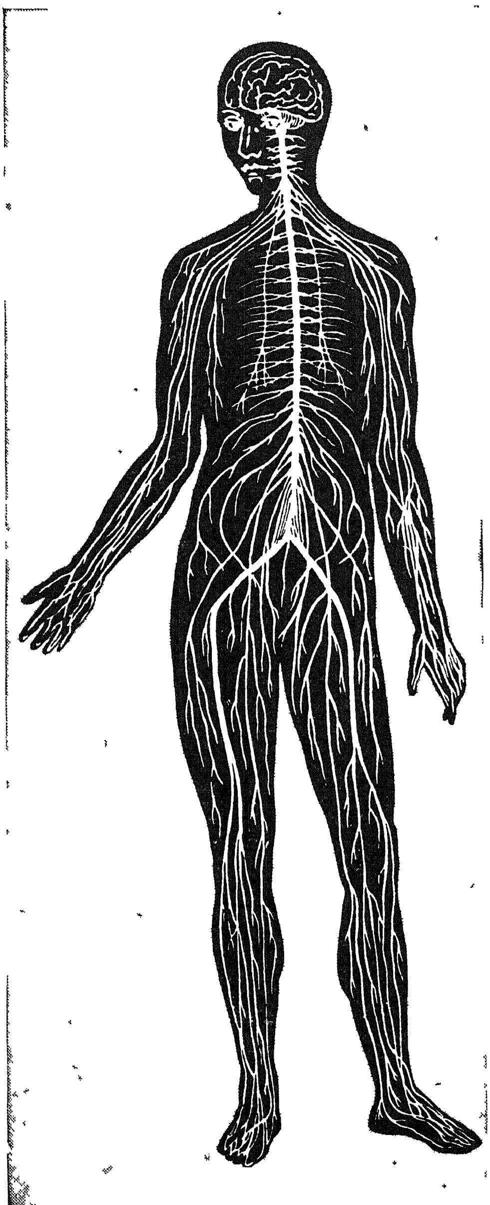
Now, it is true that the nervous system does all these things, and many more; and it has often been described in these terms, especially by the physiologists, who unravel its relations in the body and the multiplicity of its functions.

The system that exists to converse with the outer world — to feel and reply

Yet so to describe it is to miss the whole point. The nervous system is essentially a sensory-motor or reflex apparatus — with modifications, as we shall see — which exists for conversing with the outside world. It is required to feel, to perceive, to remember, to consider, to reconsider, to ignore, to refuse, to delay, but finally, and in the upshot, to reply — even by not replying. The natural sequence is to feel and to reply. The other terms we have inserted are very important, and explain why the nervous system is really so complicated. But, however many terms and stages and varieties of psychical action we interpose between sensation and response, these are the two essential terms.

And, as a matter of fact, simple acts, involving only these two terms, are constantly being performed by the nervous system of man, just as in the humblest kinds of nervous apparatus that are known. The sensory stimuli, as they are called, may proceed from the outer world, or from

the inner outer world, which is the rest of the body — outside the nervous system, but not outermost. The replies may involve only some act in the body (which is, so to speak,



THE CEREBRO-SPINAL NERVOUS SYSTEM OF MAN

the immediate environment of the nervous system), or may involve some act upon the really external world. But the act is essentially reflex or sensory-motor. We could not maintain our lives for more than a few seconds if these reflexes were not constantly at work. *We* are not aware of them, and from *our* point of view we may call them "unconscious" or "automatic" or what not, but some of our nerve-cells are certainly aware of them, as we should realize only too well if those nerve-cells failed in their duty. The problem of drawing great distinction between such of our nerve-cells and ourselves is too difficult for the present and may fortunately be deferred.

The almost infinite activity of the nervous system — conscious and unconscious

The fact remains that the nervous system, alike during sleep and waking, attention and inattention, conscious activity or repose, without intermission from its first prenatal activity until death, is always performing an almost infinite variety of reflex actions without our conscious assistance — which in many cases would be disastrous, and in many others is actually impossible. We have said *almost* infinite, and the qualification is necessary. When sensory-motor arcs are to be numbered by millions, and when almost any sensory half may be combined with almost any motor half, obviously the number of actions is enormous, but it is neither infinite nor indefinite. All these actions are anatomically conditioned. They depend upon the machinery that exists; and though that machinery is very adaptable, it has its limits It is not until we reach the highest and latest part of the nervous system that we shall reach the possibilities of the infinite.

We shall see, in due course, how this machinery becomes developed in man, so that he is capable not only of complicated actions but also of delay and reflection and invention and introspection. But no psychology, scientific or mystic, can obscure the truth which modern study of the nervous system and of man as a whole so clearly teaches — that the nervous system is sensory-motor, made of action. All sound systems of thought, and even of ethics and religion, have preached this truth.

Stoicism may have denied it, but stoicism has always led to its own destruction, as such a suicidal doctrine should. The other

systems have taught that man must feel and must act, that the highest type of man is he who feels deepest and acts best, that merely to feel and not to act is contemptible or dangerous. It is not good to cultivate sensation for the sake of sensation, emotion for the sake of emotion, or art for art's sake. These things exist, and have their ultimate justification in conduct Tragedy, as Aristotle said, should purge the soul with pity and terror, so that its deeds are fairer thereafter — not that we may say "How thrilling!" and go away with our conduct as selfish and pitiless and proud as ever.

The biological theory no less clear in its teaching than the ethical

Such, very briefly, is the ethical teaching of this theory of the nervous system. Its biological teaching is no less clear. Life is something that tries to act on inert matter, and achieve a purpose of its own This it does in plants that have no nervous system, in animals that have none, and in those that have It is just the same in man His nervous system is simply the finest apparatus of the kind hitherto evolved. Our problem is to state its special qualities without losing hold of the anatomical facts. It has all the reflex possibilities, in the first place. Its many sensory-motor arcs are so evolved that the nervous system is capable of feeling and of responding automatically in a vast variety of ways. In the spinal cord and the lower part of the brain of man we find a large number of "nerve centers", each of which is a group of cells that may be "got at" by a variety of sensory paths — from the eye, the skin, the stomach, the ear and so on. These motor mechanisms, which we have not constructed for ourselves, are at our disposal. They wait only for a signal to release, or set going, the corresponding action. Thus we strike or cry or laugh or flinch or walk or breathe or grasp, etc., by setting these prepared nervous mechanisms in motion, or by letting them go. In ourselves their number and variety and their modifiability and adaptability are unique.

But, as we shall see more clearly when we come to study the will, this part of the nervous system constitutes only one-half its excellence in ourselves Above — literally above, when we stand in the "erect attitude" — this unrivaled assemblage of sensory-motor mechanisms is a newer, subtler apparatus which is the machinery of the will, and it is will that determines what use the prepared mechanisms beneath it shall be put to Indeed, the will is quite capable of manufacturing new mechanisms by modifying the old ones, and re-piecing them so that we learn and acquire all sorts of habits, good, bad and indifferent. Short of that, the will is concerned either to choose the particular mechanism it will employ, or to combine them for special purposes; and it can decide at what moment it will release the machinery Many of our acts are thus voluntarily delayed reflexes; we did not strike our enemy when we might, but we "get back" at him later And thus the will of an animal, and preëminently the will of man, "is the more effective and the more intense, the greater the number of mechanisms it can choose from, the more complicated the switchboard on which all the motor paths cross, or, in other words, the more developed its brain. Thus, the progress of the nervous system assures to the act increasing precision, increasing variety, increasing efficiency, and independence. The organism behaves more and more like a machine for action, which reconstructs itself entirely for every new act, as if it were made of rubber and could, at any moment, change the shape of all its parts."

Man's infinite choice in action through complexity of his nervous development

This, we observe, the amœba itself can do, but man displays this fundamental property of animal life in almost infinitely — perhaps in infinitely — higher degree. In him the power of choice is unique; and that is another way of saying that in him consciousness reaches its highest point.

Consciousness appears the more when creation and choice (which are closely allied) become possible; it lies almost dormant when life is condemned to automatism, and we are not ourselves conscious of our automatic acts, even though nerve-cells somewhere must have felt for their performance.

Choice and consciousness at their highest in us, and in us at our highest, are proportional to the complexity of the switchboard on which the paths called sensory and the paths called motor intersect, or the switchboard from which they can be controlled and recombined. That switchboard is the human brain, the characteristic organ of man, unique in its development in him.

But before we try to estimate the distinctive property of this "switchboard", let us be sure that we appreciate the importance of the machinery it controls. We cannot do so without a few preliminary words on the great subject of instinct. Perhaps the most serious criticism that can be passed by the biologist upon Bergson's estimate of human psychology is that he underrates the importance of instinct. We must allude to that point here because of the interpretation of instinct which we owe to Bergson's predecessor, Spencer.

The undervaluing by Bergson of concealed reflex action in man

The argument of our present chapter is that, no matter whether we look at the nervous system with the microscope, or whether we observe its mode of action, we are compelled to recognize in it a reflex or sensory-motor machine. We have further seen that reflexes may be put together, coördinated, compounded for the performance of acts that remain essentially reflex, but may yet be so complicated and prolonged through successive stages that their essential character is almost hidden.

Now, such acts are, in fact, just those which we call instinctive, and hence Spencer taught us to look upon an instinctive action as a "compound reflex action."

Nothing in Bergson's argument really excludes this view that, considered from the evolutionary aspect, as also considered anatomically, an instinct is a compound reflex. His description and interpretation of the nervous system includes such an explanation of the physical aspect of instinct. But, as we shall see later, Bergson pays little heed to instinct in man, chiefly because of his now celebrated argument, discussed in another section of this work, that instinct and intelligence are fundamentally distinct, and have run along different lines of evolution, instinct culminating in the social insects, and intelligence in man. All that must be granted, and is a great contribution to thought.

The inadequate reverence paid by scientists to the instinct retained by man

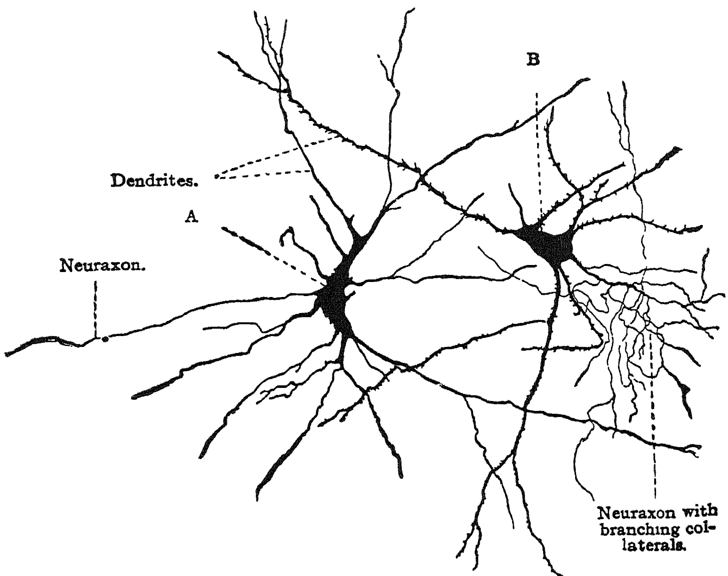
Bergson also argues that a certain portion of instinct, derived from the original powers of unevolved life, remains in the vertebrates and man, just as traces of intelligence may be found in the insects. But it is possible that if Bergson should study the subsequent work of Dr. William McDougall, which must later be discussed at length, he would modify the argument in his "Creative Evolution" to the extent of admitting much more of instinct in man.

For it can no longer be doubted that human psychology has vastly underrated the importance of instinct in man, so much so as almost to admit the sexual instinct and no more, which is truly absurd and has popularly led to very inadequate reverence for instinct in general.

The fact is that we may grant Bergson all he says about intelligence in man, and yet may allow man far more in the way of instinctive endowment than used to be supposed. The intelligence, and the highest parts of the brain, are not therefore of less account. The contrary is the truth. They are of more account because, according to Bergson's own argument, they have so many and potent and various motor mechanisms, essentially instinctive, to combine and control and choose among. As we shall show later, to deny these instincts is to leave the master of the house with no servants, and the will "free", indeed, but impotent. And the truth perceived by Herbert Spencer remains, that an instinct is essentially a compound reflex action. We shall see later that, as Dr. McDougall has shown, the action also has a side of *feeling*, and that this feeling, which we call emotion and which is the inner side of the instinctive act, has been hitherto misunderstood for lack of this simple interpretation.

But though the earlier evolutionists missed that, they were right when, through Spencer, they saw the evolution of instinctive from reflex or sensory-motor action. Only let us remember that instinct has its side of *feeling*, and we shall not run away with the too popular view that instinct is *simply* automatic, and that animals are therefore *automata*, as Descartes supposed and treated as such. That is a stupid view, and anti-evolutionary in the extreme, leaving the *psyche* of man without any natural origin.

in the ape, the brain is made to choose among the various motor mechanisms, essentially sensory-motor arcs, over which it presides. But the evident fact of man is that he can learn to do anything, as is finally evidenced by the fact that he can make any kind of object, including any kind of machinery or device, an engine or a book — which is a sort of engine, too. Hence the brain of man alone can set up an infinite number of mechanisms, so that its choice as to their employment is infinite, too. Only of a brain which can create machines outside the body could this be said. The difference, therefore, between man and his nearest rivals is the difference between the limited and the unlimited, the closed and the open. It has become a difference not merely of degree but also of kind.



From Lewis & Stohr's *Textbook of Histology*, P. Blakiston's Son & Co.

TWO NERVE-CELLS OF THE CENTRAL NERVOUS SYSTEM (Magnified 200 times.)

A, cell of Deiter's type, having a neuraxon ending at a considerable distance from the cell body; *B*, cell of Golgi's type, having a neuraxon with many branches ending near the cell body.

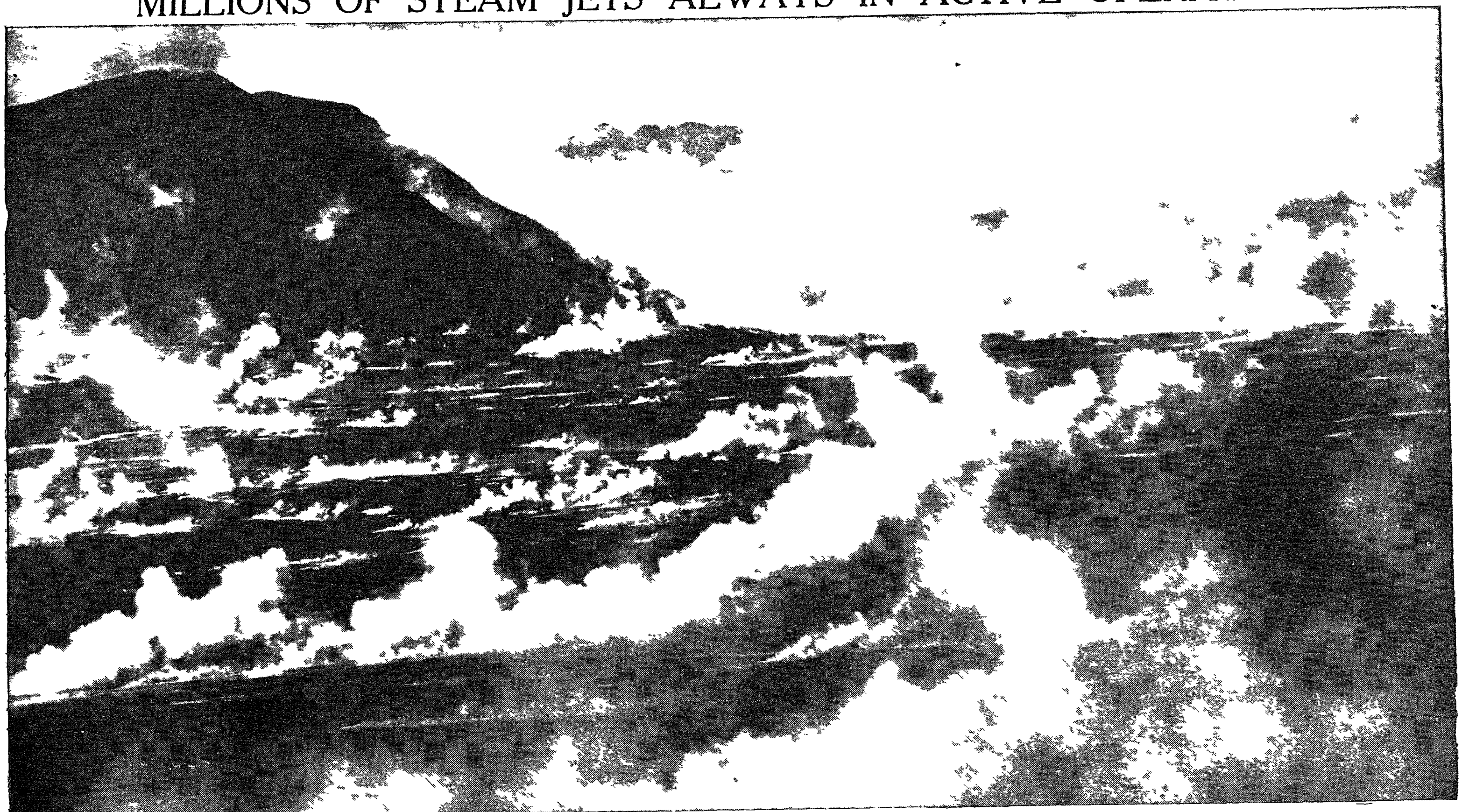
Yet, though the continuity between man and the lower animals along the vertebrate line is real, and though the nervous system of man is essentially a group of sensory-motor arcs for action, yet it does overwhelmingly transcend all its predecessors. The brain of man is so large that the quantity of choice and of consciousness which can be displayed through it is unique. But that is not all.

It really looks as if the brain in man had reached a point of capacity which causes it to differ in more than degree from its nearest rivals. Take the highest ape, and we find that, though the creature is intelligent and can learn, its powers and learning are strictly limited. In man, as

In reaching that great conclusion to the argument which began with the simple reflexes of any living being, we have also reached a fresh beginning.

We have come to the human at last, as distinguished from what is common to man and to many other creatures. The brain holds the key to all that shall follow; and this supreme organ of all life must next engage such capacities as it displays in us who write and read.

MILLIONS OF STEAM JETS ALWAYS IN ACTIVE OPERATION



THE VALLEY OF TEN THOUSAND SMOKES

This picture of one of the greatest wonders of the world was taken by the National Geographic Society's Expedition to Mount Katmai, which discovered the Valley of Ten Thousand Smokes It is taken at the entrance to the valley, which is more than seventeen miles in length No complete view from any one vantage point is possible, for so dense is the smoke that everything beyond five miles in any direction is hidden by an impenetrable white pall

FUTURE SOURCES OF POWER

An Inquiry as to Amount of Energy
of the Universe That Man May Exploit

MECHANICAL DEVICES AND MOTIVE POWER

GEOLOGISTS tell us that in time, millions of years, though, it may be from the present, the earth will be a cold and frozen planet on which life will be impossible. Although the Eskimo lives in a temperature much lower than zero, the cold to which he is subjected is as nothing compared to that of interstellar space, which is far below the point at which life can be sustained. But even if life were possible on such an earth, it is not pleasant to contemplate the state of civilization which could exist under such conditions. City life, as we now know it, would be impossible. Even today a temperature of –75°F. would seriously hamper the activities of men in most of the populated areas of the world. What would happen if temperatures sank far below that point? There would be intense suffering even if power-generating stations were far more efficient than they are today and supplies of coal and oil were inexhaustible.

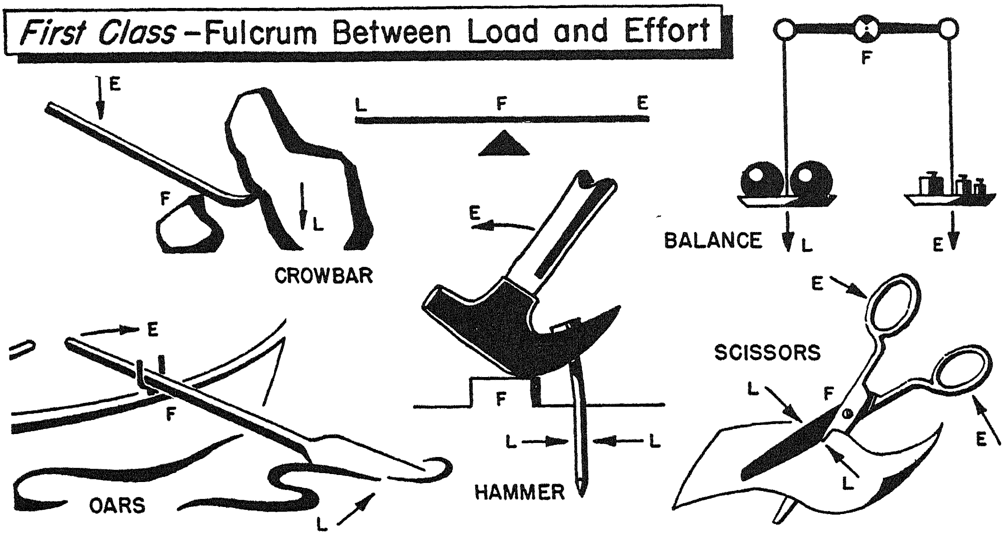
And here is the point which causes serious reflection, for the geologists also tell us that our present supplies of coal in sight will be exhausted within a time variously estimated by different scientists at from 3,000 to 5,000 years. At present mechanical energy is cheaper than animal because of the discovery and exploitation of vast coal, peat and oil fields, but we are drawing on these supplies with ever greater and greater demands and the steam and internal combustion engine are already threatening to deplete these stores to an alarming extent. Coal has been used for only about 150 years and oil for an even shorter period, and yet we are beginning to consider the time when these supplies will be entirely exhausted. It is estimated that 60 per cent of the fuel now burned could be saved by economical use, but unless new sources of supply are found, it may be that our present era will be simply a dazzling interlude between the dark ages of the past and the dark age of the future.

The difficulties of the coming generations, facing depletion and even complete exhaustion of the now common sources of light, heat and power, will be many. Man cannot create the real wealth of the world. This wealth, which consists mainly of nature's stores of fuel energy, has required millions of years for its creation. All man can do is to find the treasure, and then devise an ingenious method of using it to his advantage. Without his ingenuity the treasure is valueless. At the present rapid rate of consumption of our fuel resources, our descendants, regardless of their greater scientific knowledge and industrial skill, may be hopelessly poverty-stricken, in spite of their inheritance from us of the knowledge of the so-called "mechanical powers" and similar devices in electricity and chemistry. The industrial development of the modern era is due to our intelligent use of the six mechanical powers: the lever, the inclined plane, the wedge, the wheel and axle, and the screw. Combining these we have evolved the marvelous machines that have enabled us to exploit the immense stores of natural energy in our coal mines and oil fields.

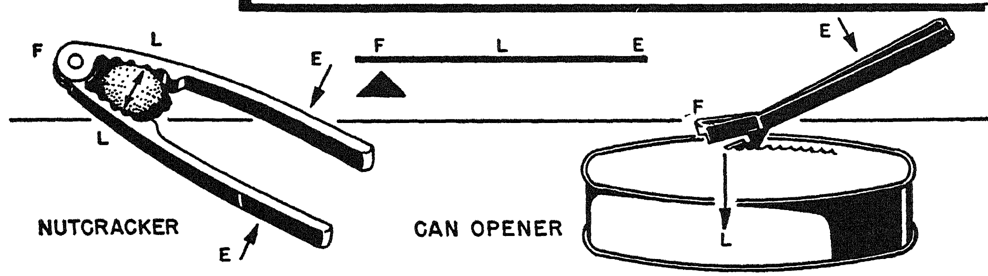
A PICTORIAL SURVEY OF THE SIX SIMPLE MACHINES

THE LEVER The machine known as the lever is a solid, rigid object that turns about a fixed point, called a fulcrum, or pivot. By exerting force at one point of the lever, we can apply a greater force at another point. There are three classes of levers, as is shown below. In the illustrations, E stands for effort, F for fulcrum and L for load.

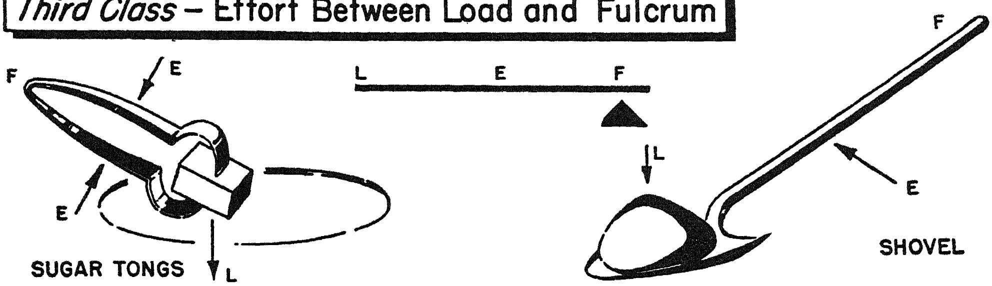
First Class – Fulcrum Between Load and Effort



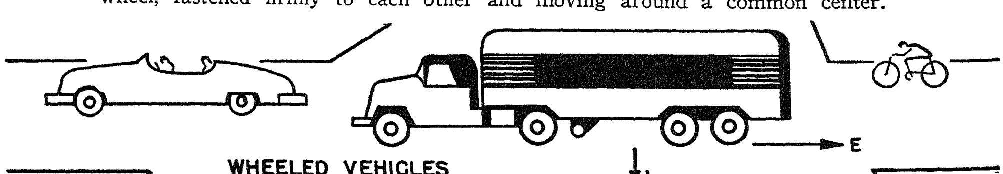
Second Class – Load Between Fulcrum and Effort



Third Class – Effort Between Load and Fulcrum

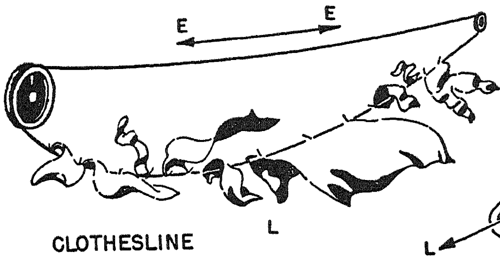


THE WHEEL AND AXLE This consists of a large wheel and a smaller wheel, fastened firmly to each other and moving around a common center.

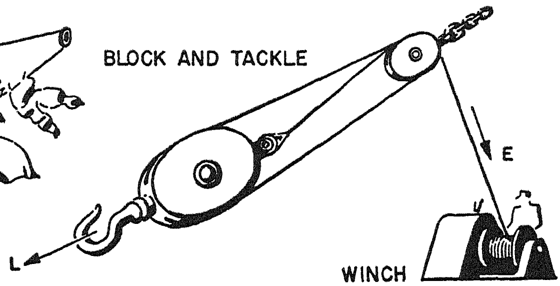


THE PULLEY

This machine consists of a rope or chain that is slung around a wheel or series of wheels. When large weights are to be lifted, a combination of pulleys, called a block and tackle, is employed.



CLOTHESLINE

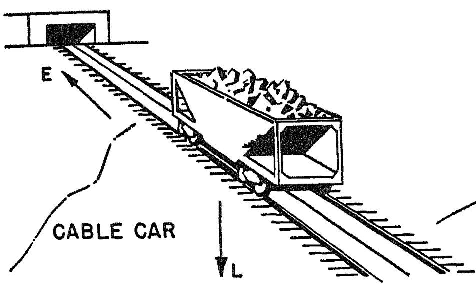


BLOCK AND TACKLE

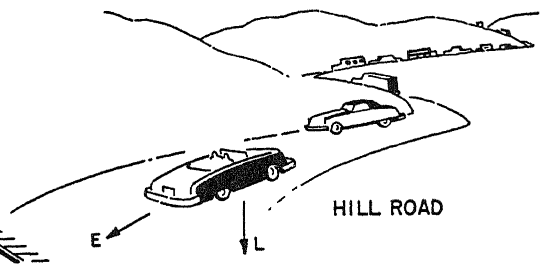
WINCH

THE INCLINED PLANE

An inclined plane is a sloping surface. Bodies that are too heavy to be lifted straight up can be moved much more easily up an inclined plane.



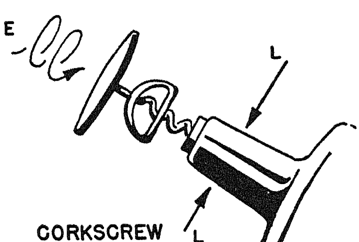
CABLE CAR



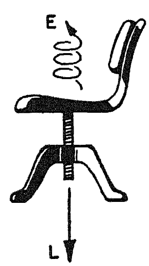
HILL ROAD

THE SCREW

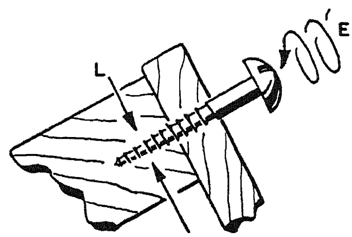
This is really an inclined plane that winds all around a central shaft. Whenever this central shaft makes a complete turn, the screw is moved the distance between two successive threads.



CORKSCREW



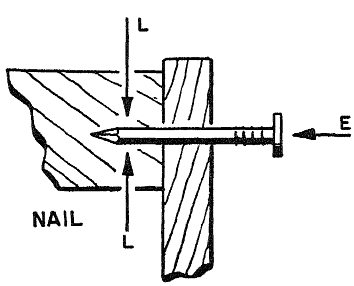
SWIVEL CHAIR



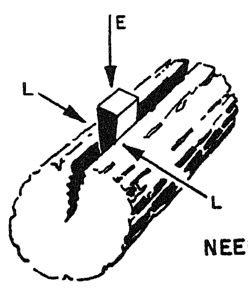
WOOD SCREW

THE WEDGE

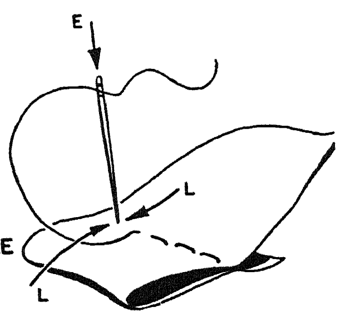
Two inclined planes having a common base — that is the wedge. It exercises strong pressure when forced between two objects. Needles, knives, chisels and nails all utilize the wedge principle.



NAIL



WEDGE



NEEDLE

Exploitation, however, is not creation. One word more in connection with the mechanical powers. Many people undoubtedly are under the impression that the lever, inclined plane, etc. add to our energy resources because with them we can accomplish tasks otherwise impossible. But the definition of energy, "capacity for doing work", shows that the lever is not a source of energy, but simply a means of utilizing energy in a more convenient manner. Work is a measure of energy, and work in English units is measured in foot-pounds. If a man moves one end of a lever a distance of two feet while pushing with a force of 100 pounds, he does 200 foot-pounds of work. At the other end of the lever there can be obtained only 200 foot-pounds of work. This may be 200 pounds moved one foot, or 400 pounds moved half a foot, or 2000 pounds moved one-tenth of a foot, but the product of the weight and the distance moved can be only 200 foot-pounds.

All known machines of man's invention require work to overcome frictional and other resistances. The lever, balanced on a knife edge, is the only mechanical power which gives back practically all of the work done on it. The screw-jack, by which a man may lift an automobile, is another example of a small force applied *to* the mechanism and a large force exerted *by* the mechanism. The man's hand at the end of the bar applies a small force and moves many feet in one turn, while the automobile, which weighs perhaps two tons, is lifted only a short distance. Friction in a screw-jack is a fairly large item, hence the force exerted by the man, multiplied by the distance his hand moves, is much larger than the product of force exerted by the jack and the distance the object is lifted. That is, the work done *by* the jack is less than that done by the man *on* the jack.

No machine has yet been devised which gives out more work than is put into it and none ever will be despite the deluded unfortunates who waste their time and money on perpetual motion machines. No machine, furthermore, will give out as *much* work as is put in, for we always have to contend with the loss by friction of the bearing surfaces; hence, the net work to be taken from a machine will be that put in less that required to overcome the resistances of driving it. At best a perpetual motion machine would be merely a curiosity, a perfect machine which gives back as much work as is put into it, no loss having taken place in the machine. By putting the work done by the machine back into itself it would run forever, *provided* the materials of which it was made did not wear out. But, assuming the machine to be everlasting, if we should try to drive an electric generator by the machine, the latter would promptly stop because we should be attempting to get more work out of it than it had put into itself.

The electric transformer is analogous to the lever. By applying a small current under a high voltage to one side of the transformer, we may take a large current at low voltage from the other side. There is no gain in energy; there is a loss, for the resistance of the wire to the flow of current has to be overcome.

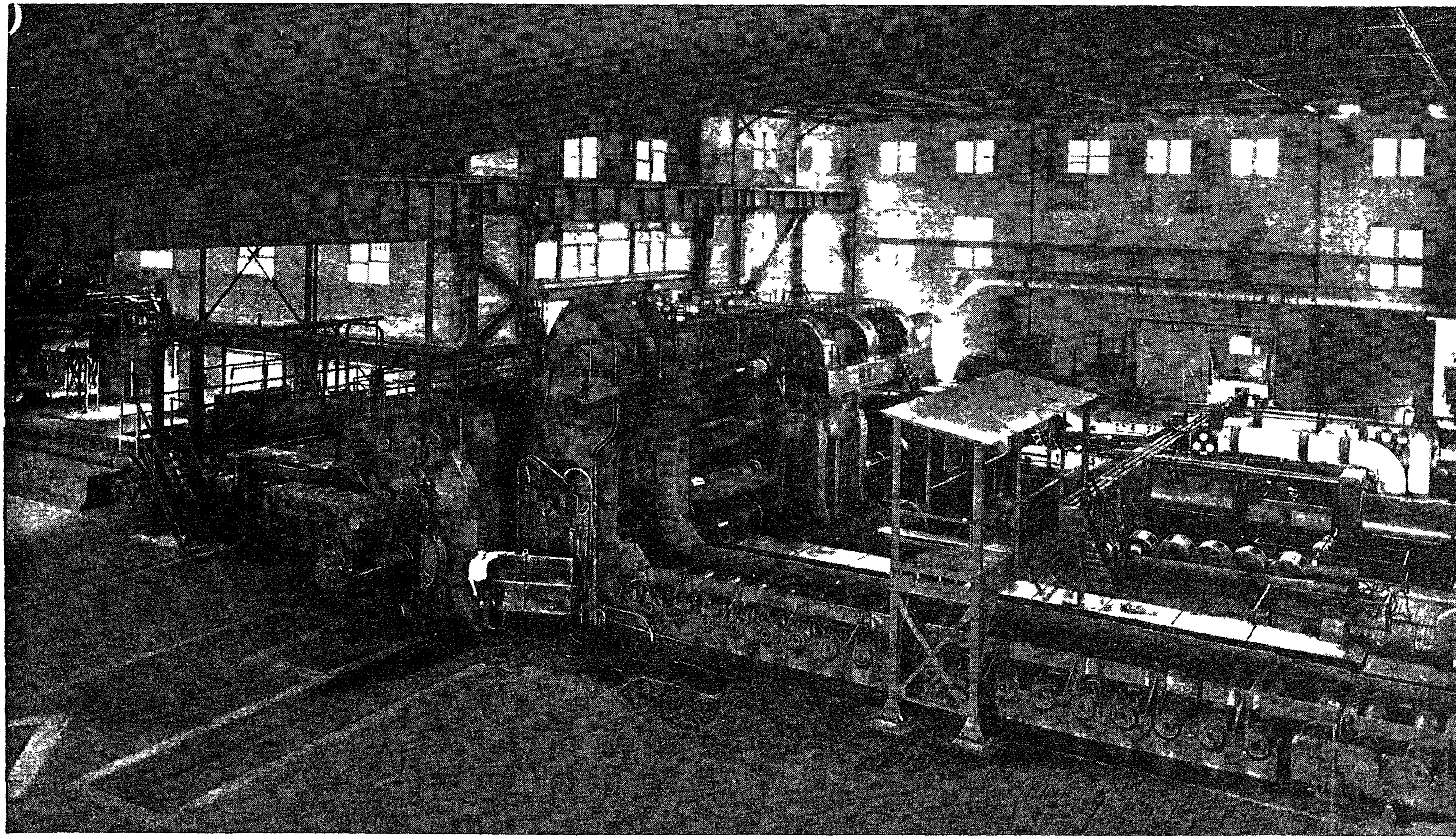
As has been mentioned, the operation of machines is always attended by a loss of energy in overcoming friction. To a large extent this loss can be eliminated by the use of proper lubricants. In the present age of high speeds and high temperatures, mineral oils are the only lubricants which will stand the strain imposed on them. In using them man is drawing on a natural source of energy.

Let us take stock of our sources of energy and then discuss them separately. For industrial purposes energy is derived from:

(1) The muscular power of men and animals
(2) The radiant energy from the sun
(3) The energy of the winds
(4) The internal heat energy of the earth
(5) The energy of fuels
(6) Chemical energy
(7) Gravity and gravitation

Strictly speaking, all but the last of the above sources of energy may be referred back primarily to the sun.

A MARVELOUS MONSTER MAN-MADE MACHINE



This illustration shows the 46-inch slabbing mill equipped with vertical in addition to the horizontal rolls for treating steel. It was built by the Mesta Machine Company of Pittsburgh. The horizontal rolls are 36 inches in diameter and 84 inches in length. An ingot weighing 50,000 pounds is rolled back and forth through them until it has a section area of 20×60 inches. The vertical rolls keep the edges square with the top and bottom surfaces. The total weight of this mill, including engines, is approximately ten million pounds. The figure of the man in the foreground will give an idea of its size.

The muscular power of men and animals

In ancient and in slavery times the work of man as a machine was of considerable importance. Undoubtedly the Pyramids and great temples of the Egyptians were built with manual labor aided by the lever and the inclined plane.

The comparison of work done by various machines is based on that done by the horse, determined by experiments made years ago by James Watt. The supposed ability of a horse to do 33,000 foot-pounds of work per minute is a rating far too high for his continuous effort and can be sustained for only short periods. A much fairer figure, as far as the horse is concerned, would be 25,000 foot-pounds, but in the comparison of engines with each other, 33,000 does as well as any other arbitrary rate. When we consider that some of our large engines can do work equivalent to that of 5000 horses, it makes little difference whether 3000 or 7000 horses would be required to do the same work.

Experiments made by various observers on the work done by man in pushing, pulling, carrying and lifting weights seem to indicate that one-tenth of a horse-power is about the limit in rate for a man working eight hours per day. For short periods $\frac{1}{3}$ horse-power has developed, but for continuous work throughout the day a man is probably most efficient when working one-third of his day of 24 hours at a speed and exerting a force one-third of his maximum.

Radiant energy from the sun

The radiant energy of the sun is responsible for the vegetation of the earth which makes animal life possible. This vegetation in millions of years gone by has formed our coal and peat. The snow and rainfall are due to the sun, which has lifted from the oceans and lakes water which later falls back to earth and gives us our brooks and rivers. The water of these streams in its flow toward the sea is a source of energy. The winds are due to solar energy, for air rising from a heated region produces a lowering of atmospheric pressure toward which air flows from colder parts of the earth.

Taken directly in the form of heat, solar energy undoubtedly may be used for the production of power. The Eastern-Sun-Power Company operated in 1913, for irrigation in Cairo, Egypt, an engine driven by low-pressure steam generated in a boiler heated by the sun's rays. Reflectors were so placed that the sun's rays were concentrated, and directed against a zinc boiler covered with heat absorbing paint. The reflector was moved to follow the sun's motion, and thus keep the rays always on the zinc boiler.

Dr. C. G. Abbot, of the Smithsonian Institution, recently made great improvements. He used permanently bright parabolic cylindric mirrors of aluminum products. These rotate slowly around and focus sunrays onto small boiler tubes of blackened copper surrounded by transparent evacuated glass sheaths having the property of thermos bottles to retain heat. Only sufficient water to flash totally into steam at the desired pressure is forced into the boiler tubes, which lie parallel to the earth's axis. Full steam pressure comes within five minutes, hence partly cloudy days are useful. Fifteen per cent of the energy of the sun's rays striking the mirror may be converted into effective mechanical work.

New Mexico alone would be able to furnish more solar power than the total power produced in the United States from all other sources. A not insuperable objection is that nights and cloudy days would require power storage.

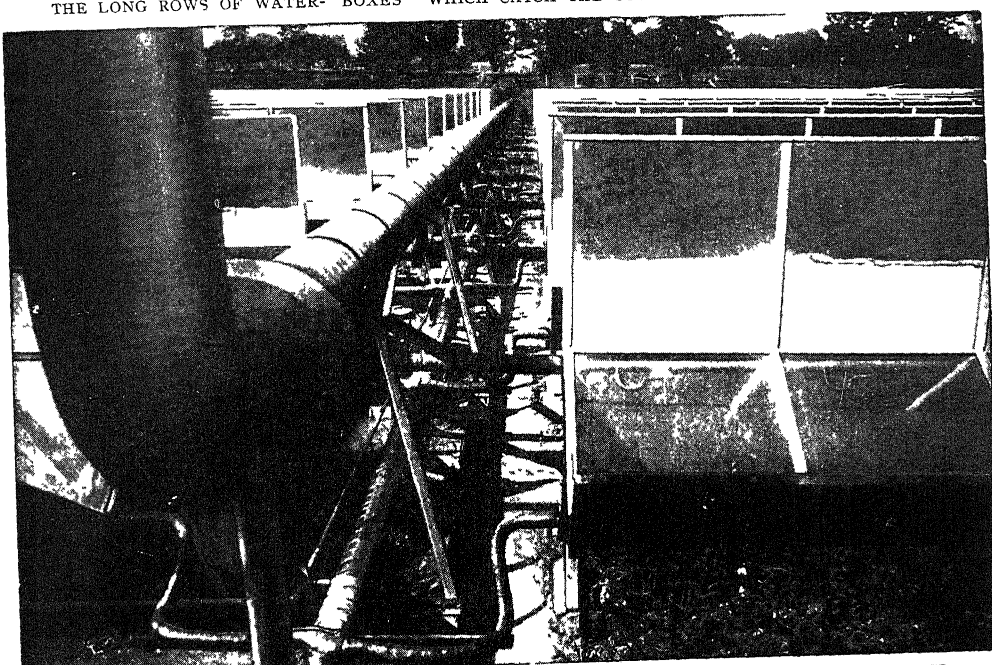
Dr. Abbot also cooked food and distilled seawater with somewhat similar solar devices. Experiments on solar househeating were made at the Massachusetts Institute of Technology.

The energy of the winds

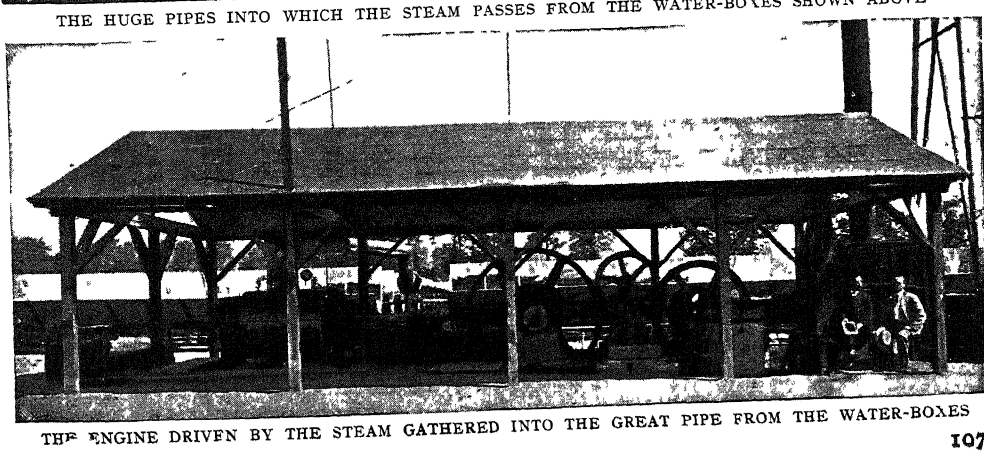
Primitive man by stretching a sail of skin used the energy of moving air to propel his rude craft, and today ships with four, five and even seven masts are sailing the oceans. If engines were used to drive them we should find from 1500 to 5000 horse-power necessary.

THE SUN'S RAYS HARNESSED TO AN ENGINE

THE LONG ROWS OF WATER-"BOXES" WHICH CATCH THE SUN'S RAYS TO GENERATE STEAM



THE HUGE PIPES INTO WHICH THE STEAM PASSES FROM THE WATER-BOXES SHOWN ABOVE



THE ENGINE DRIVEN BY THE STEAM GATHERED INTO THE GREAT PIPE FROM THE WATER-BOXES

In the twelfth century windmills came into use. Holland is still dotted with them, and in an improved form the windmill may yet become an important device for obtaining mechanical power Like the solar engine the windmill is intermittent in action, for the winds are contrary and may or may not blow. Until some way is devised for storing up energy to be used in calm periods, the windmill cannot become a dependable source of power. Reports of the U. S. Weather Bureau show that rarely over 3000 out of a possible 8800 hours in the year is there a favorable wind of 10 to 20 miles per hour for their use Higher is likely to injure the mill.

The internal heat energy of the earth

Scientists have often been attracted by the possibilities of utilizing the heat of the earth's interior for power purposes on the surface. Not many years ago the famous French astronomer Camille Flammarion proposed to sink a huge shaft into the earth and use the heat thus obtained for driving engines. In the digging of such a shaft there would probably be no insurmountable difficulties, but for 100 H.P. it would be necessary to sink such a shaft three miles below the surface and make it almost 600 feet in diameter. Such an undertaking would be unbusiness-like, to say the least

The nearest approach to such a shaft is the utilization of steam generated by volcanic heat. In 1917 Professor Luiggi of the University of Rome reported that three 4000-H P. plants were operating in Tuscany, using the heat from steam formed underground. From numerous fissures in the side of a mountain from which the steam issued, iron pipes 15 to 20 inches in diameter were driven down 300 to 500 feet into the ground. This steam direct from the point of generation, and under pressures of from 30 to 75 pounds and at a temperature from 300 to 375° F., was used for driving a low-pressure turbine of special design. Frequent repairs, due to the action of borax salts and hydrogen sulphide gas, have led to a change in the method of using the steam. Previously it went from the ground directly in the turbine, but now it serves as the heating agent in a specially designed boiler, following which

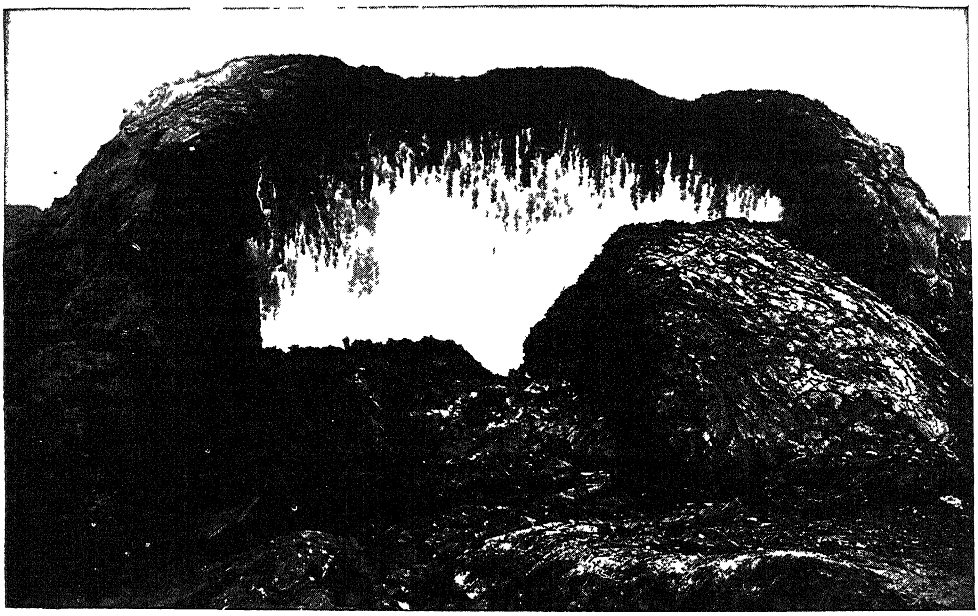


Photo Ewing Galloway, N Y

COMMERCIALIZING VOLCANIC HEAT

Remarkable close-up view of the white-hot fire hole in the volcano of Kilauea on the island of Hawaii The Volcano Research Association is to drill deep into the hardened lava about the vent to determine whether the heat is sufficiently regular to be used for generating power.

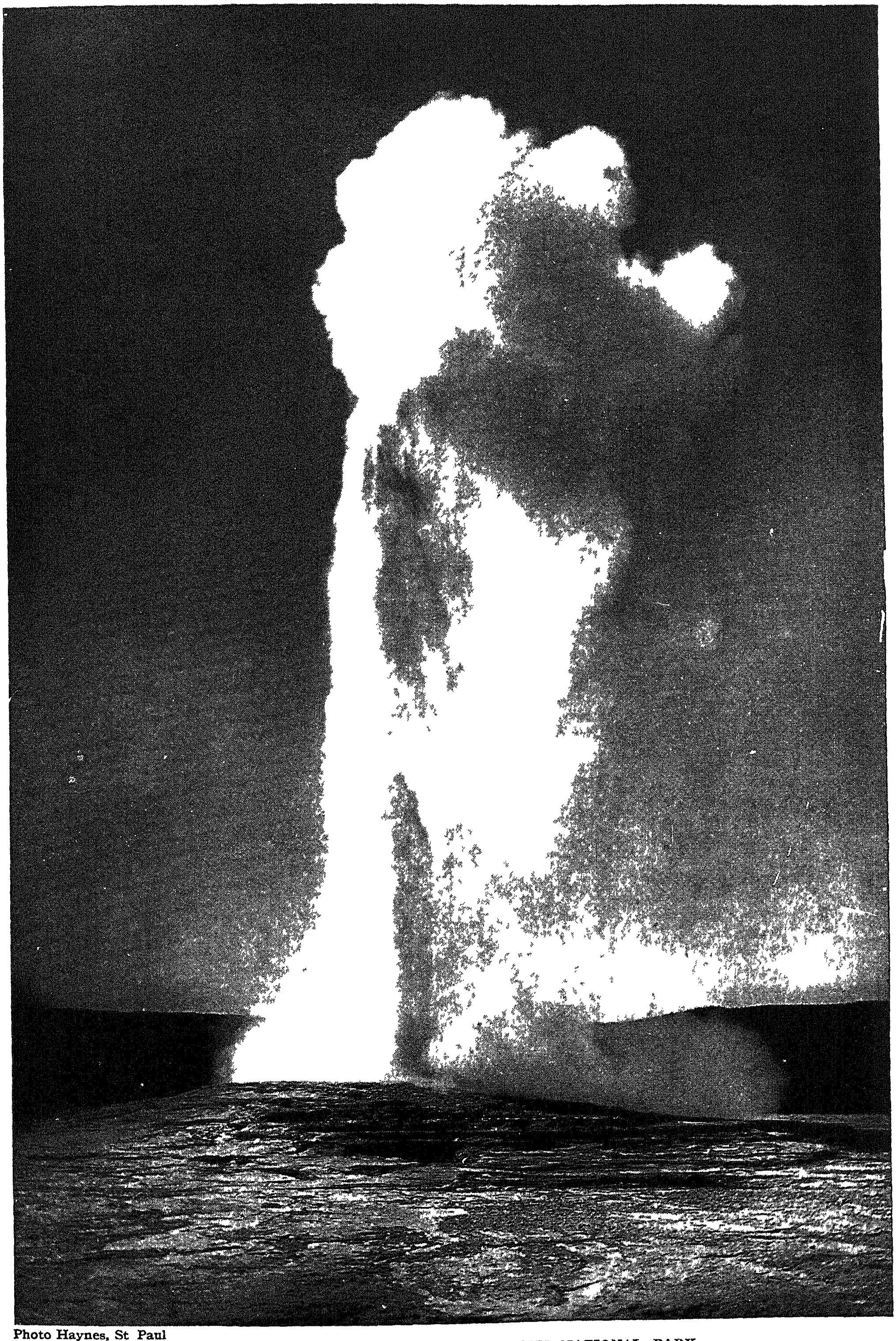


Photo Haynes, St Paul

OLD FAITHFUL GEYSER, YELLOWSTONE NATIONAL PARK

SAFETY VALVE FOR EXCESS STEAM FROM THE INNER EARTH

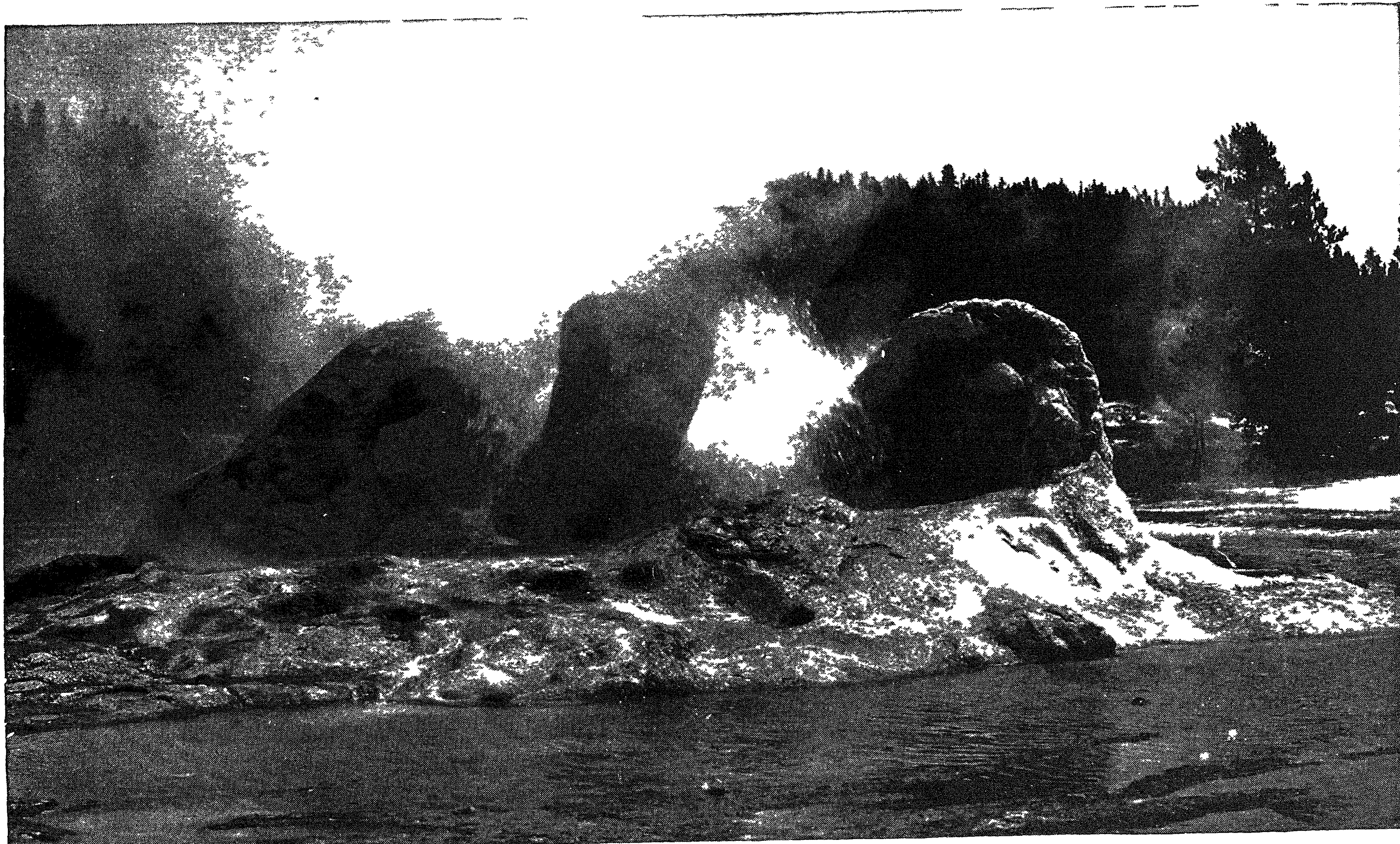


Photo U. S Department of the Interior

GROTTO GEYSER IN ERUPTION, UPPER GEYSER BASIN, YELLOWSTONE NATIONAL PARK

Photo Publisher s Photo Service

GIANT GEYSER IN WINTER, YELLOWSTONE NATIONAL PARK.

© E M Newman

STEAM ESCAPING FROM CREVICES ON MAUNA LOA, ISLAND OF HAWAII.

it passes through an economizer for heating the feed-water. Fresh water can thus be used for making steam for the turbine, and pressures of about 30 pounds are available. The turbines are connected to electric generators which give 6500 volts. Oil transformers advance the voltage to 36,000 and the high voltage transmission lines carry the electricity to the surrounding small towns for power and lighting. During the war, the power was used by day for munition factories and at night a small part was available for lighting purposes in the town. An additional 100,000 H.P. is still possible in such districts by continuing the development of power in the manner described. In the United States there are to be found in Yellowstone Park numerous opportunities for just such exploitation of the earth's interior heat, and without question sufficient power for the whole Pacific Coast could be developed.

Chemical energy

In the chemical combinations of the materials of our earth we have such a vast tract of unexplored knowledge that it is not unlikely that chemists and physicists will, by their achievements, place new and tremendous sources of power within the reach of the engineer. If the cost of suitable material was not prohibitive, the energy of chemical combinations could be used for obtaining electricity directly. In the electric battery we have an example of chemical change producing a motive force. Since Alexander Volta showed that electricity could be generated simply by heating two different metals in contact with each other, new ideas for the production of power have excited the imagination of scientific men. The electrochemical methods of exploiting some of the main sources of power present many and great advantages over the heat methods that are still in general use.

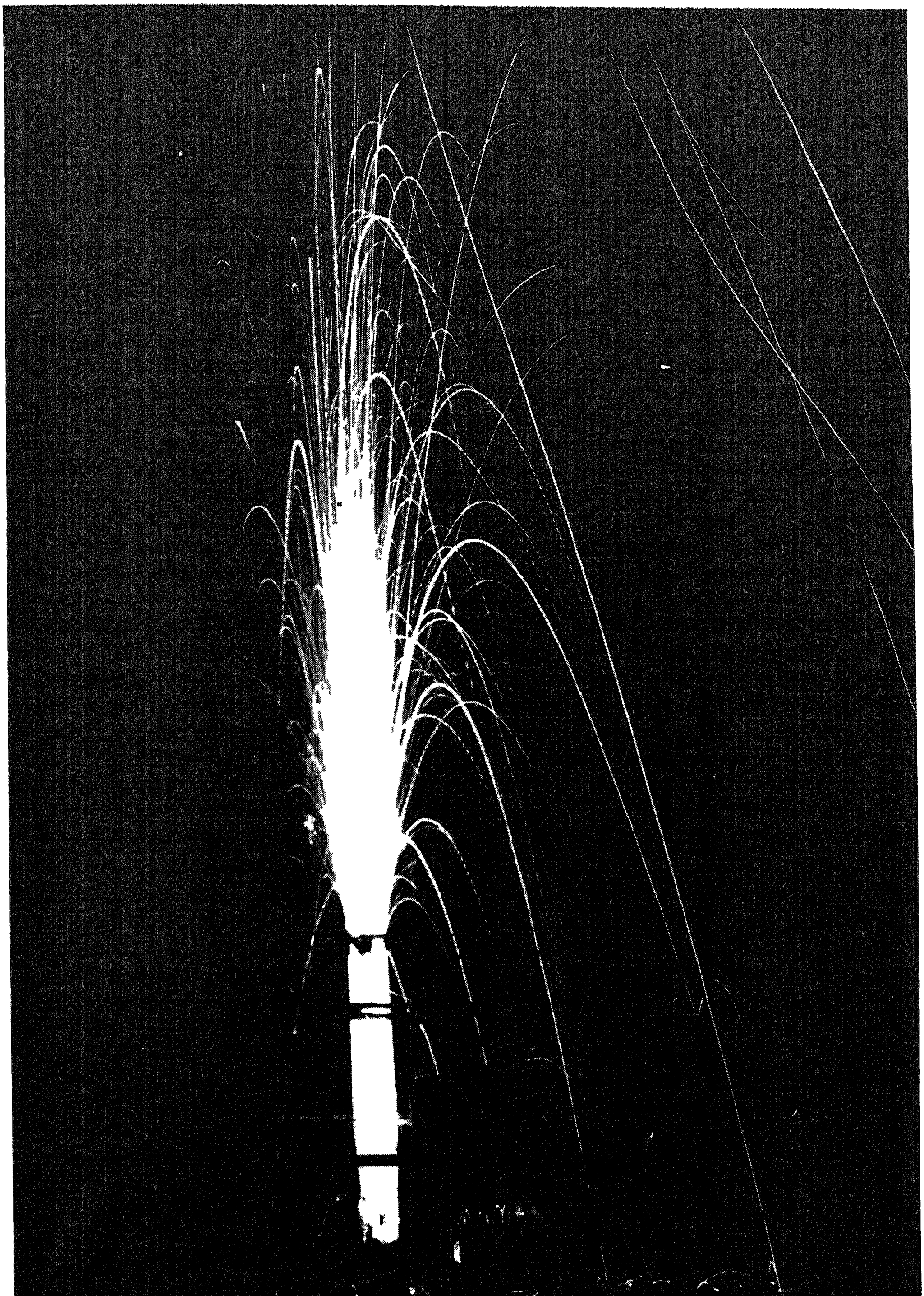
In heat methods we change chemical energy into heat, then heat energy into mechanical energy, and most of our electricity is obtained by further transforming mechanical energy into electrical energy. In many city homes we have gone backward from this point and have changed electrical energy back into heat energy, a most costly method of getting heat when it could have been obtained directly from the same kind of fuel used by the electric lighting and power company under its boilers. However, the convenience and cleanliness of heat obtained through electricity is sometimes the determining factor in its use.

Were it possible to use the carbon of coke directly as the positive element of an electric battery, a much greater proportion of the natural energy of coal could be turned directly into work than now is; but, unfortunately, though slight success has been attained in such use, carbon is very nearly at the bottom of the list of possible elements for a battery, and being electronegative to all but a few others, the choice of a suitable negative element is limited. The construction of batteries using coke as the positive element is costly and cumbrous, and though methods have been devised by Reed and Jaques for such use, the voltage is low and it is unlikely that the power problem will be solved along this line.

There are among the chemical elements certain ones, notably platinum, which hasten the chemical combination of two substances. For instance, a pinch of powdered platinum will suddenly turn sulphur dioxide into sulphuric acid without any loss or change whatever in the platinum. Numerous other instances might be given, but the most common is found in the little pocket cigar lighter in which a very fine platinum wire, when held over the vapor of alcohol, becomes red-hot and ignites the vapor. This action is called "catalysis" and the platinum is the catalyzer. Possibly a catalyzer may be found which by its action will quickly release the energy of substances which now requires years.

The wonderful advance of synthetic chemistry now makes it possible to manufacture gasoline from coal by means of hydrogenation at high temperatures and pressures. Without doubt many other stirring developments lie ahead. Nothing that the chemist may discover will much surprise us, to such wonderful things in the recent past has he accustomed us.

FUEL GAS FROM COAL IN THE GROUND



Bureau of Mines

Like a fireworks display, burning gas shoots skyward from a borehole at the coal-gasification project at Gorgas, Alabama. By burning coal in its underground seams, men can produce fuel gas cheaply.

The energy of fuels

Before taking up fuel energy it should be noted that in burning coal, wood, oil or any other substance, a chemical process is undergone, for burning is simply a rapid combining of the substance with oxygen. The chemical combination of carbon with oxygen in the furnace under a boiler produces the heat necessary for turning water into steam.

Wood, the first of man's fuel stores, once so abundant in the world's vast forests, has been recklessly, even criminally, wasted Until it was realized that coal was a more suitable fuel for industrial power purposes, wood was burned under steam boilers. In certain localities it is still used, not in preference to coal but because it is near at hand and costs to cut and haul less than the transportation alone of coal. But the greatest destruction of our forests by the hand of man has been due to the enormous use of wood pulp for paper-making. So flagrant was the abuse in denuding wooded tracts, so profligate the exploitation of timber land, that the government has had to limit the amount of lumber which may be cut. By careful thinning out of the trees, it is possible to keep the remaining timber growing, but when completely stripped, as thousands of acres have been, there is no hope of future growth, for with nothing to retain the rain the water runs off the hills and mountain sides as fast as it falls, giving no sustenance for vegetation. Dry brooks become raging torrents for a brief period and then subside until the next storm. This fact will again be mentioned when we come to consider water-power.

There is enough coal in the ground to last us for several thousand years, reckoning with known reserves; furthermore, other coal fields will undoubtedly be discovered in the future. Unfortunately, however, some of the world's coal deposits are so inaccessible or so far from the place where the coal would ultimately be used that the cost of transportation would be prohibitive. In other cases the coal seams are too poor in quality to justify mining operations. In order to eliminate the cost of the mining and transportation of coal, attempts have been made to burn unmined coal as it lies in the earth and to utilize the combustible gases produced in this way.

In 1947 the United States Bureau of Mines and the Alabama Power Company began a series of experiments in this "gasification" of coal at Gorgas, Alabama. The engineers in charge of the operation first drilled from the surface through the layer of coal; a fire was then started by dropping an incendiary bomb in the hole formed in this way. Air was forced down the hole in order to feed the fire. As the gases which resulted from combustion rose to the surface, they were trapped and piped to storage tanks. Gases produced in this way can be used to fire a boiler or to make synthetic liquid fuels. Although the gasification of coal is still in the experimental stage, it offers great promise for the future.

The United States, Mexico and Russia have enormous oil fields. Oil, because of its ease in handling, its cleanliness, its convenience in storage, and its higher heating value for the same weight, is coming into extensive use, not alone for our ships on the sea, but also for stationary power plants.

The lightest distillates are used for the internal combustion engine, which is demanding an ever increasing supply, so great, in fact, that the gasoline of today is nearly as low in volatility as the kerosene of ten years ago. With improved devices for mixing air with it and vaporizing the liquid fuel, we may expect this lowering of the volatility to continue. The introduction of "fuelizers", "hot spots", and other preheating appliances have already accomplished wonders. The Diesel engine proper, which operates with the heaviest of the mineral oils, and its near relative, the Semi-Diesel, which burns kerosene and even heavier distillates, are demanding only a fraction of their ultimate needs. Mineral greases and oils for lubrication, road construction, etc., are also drawing on the available supply. Fortunes are made overnight when oil is discovered, but though new wells are driven every hour in the day the demand still exceeds the supply.

THE THUNDERING CATARACT'S FORCE

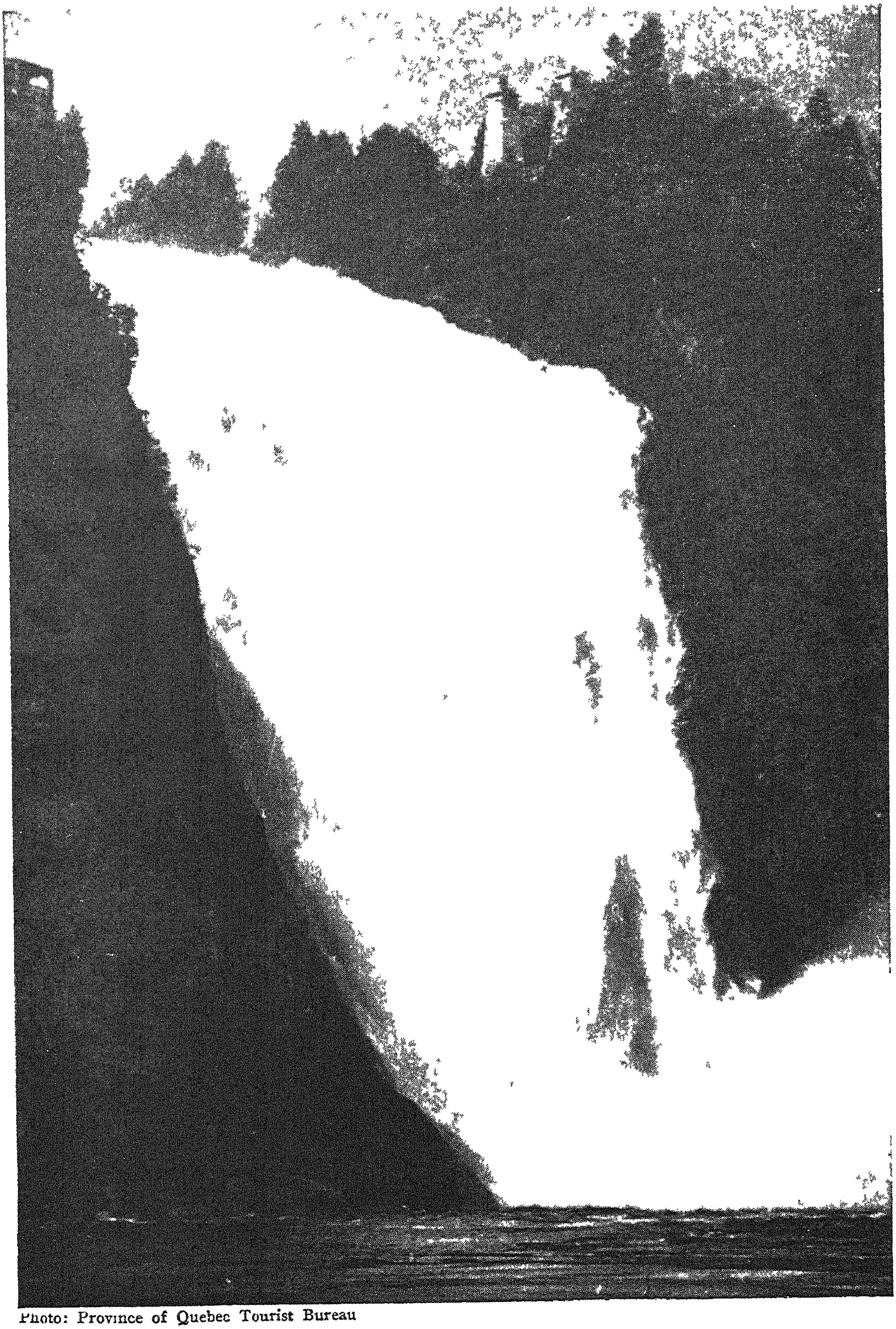
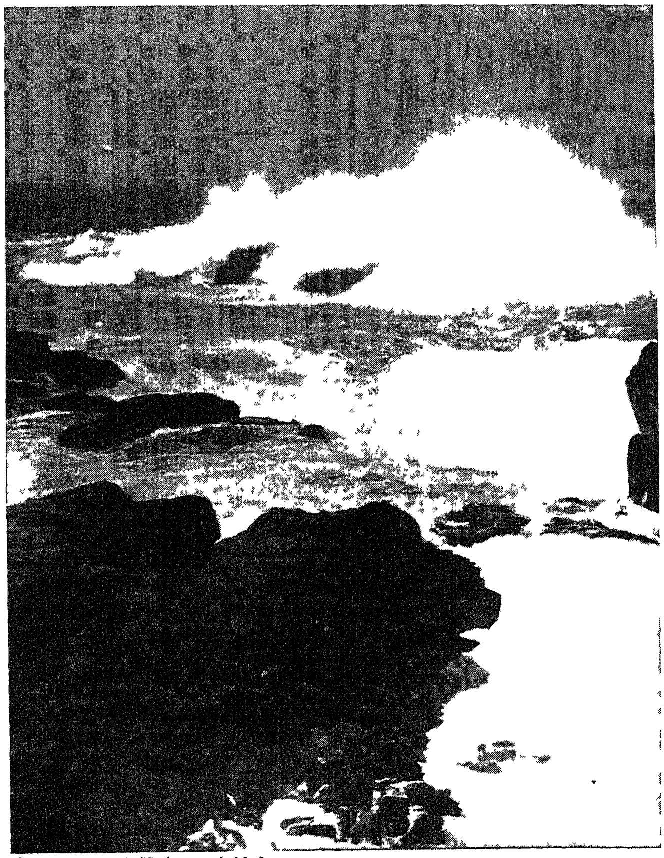


Photo: Province of Quebec Tourist Bureau

MONTMORENCY FALLS

Gravity and gravitation

Gravity is the pull of the earth on bodies, while gravitation is the pull of one body on another. For example, if two apples on strings are suspended from a beam, the pull of the earth on the apples is due to gravity; the pull of one apple on the other is due to gravitation. In small masses the attraction of gravitation is small, nevertheless it can be shown by the physicist by extremely delicate instruments. When we consider masses such as the earth, the moon, the sun and the other members of the solar system, it can be seen that enormous forces are at work. The action of the tides is due to the pull on our earth exerted by the moon. Probably the ground itself is somewhat distorted by this pull, but not being fluid, as is the ocean, we do not notice it.



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THE ENERGY OF THE WAVES

Surf beating on the rocks at Mollendo, Peru.

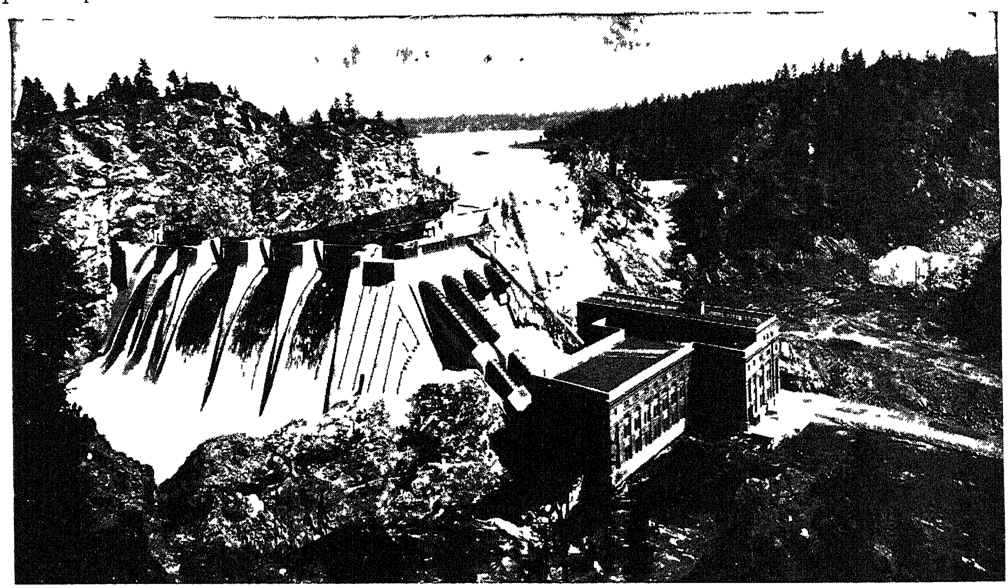
Tidal energy has long been utilized and the most successful tide machines have been those taking advantage of the rising tide for storing water in tanks or basins, from which it is passed through old-fashioned, undershot water wheels or turbines. At Rockland, Maine, however, is a 5000-H.P. plant using the tidal water for compressing air, which is then employed instead of steam for driving an engine. There are two shafts sunk in the earth to about 200 feet, connected at the bottom by a horizontal tunnel. The water falls through one shaft and rises through the other. Air, carried down with the falling water, is compressed to almost 85 pounds. At the bottom of the shaft the air is separated from the water and rises through a 14-inch pipe to the engine.

The water turbine has increased the power obtainable from tidal basins. It would be out of the question to construct by excavation tidal ponds for large power plants, but there are many natural basins which would need only to be closed in by a sea-wall in order to be converted into power reservoirs. French engineers have estimated that the tides at Honfleur, at the mouth of the Seine, might be utilized to yield power at a cost of about $60 per horse-power per year. This compares favorably with the power cost of a steam plant using coal. Experiments have been made on the Schleswig-Holstein and on the north German coasts with tidal power, and there are numerous small plants on the shores of Connecticut and New York. There are few places which have a tidal rise of over six feet. With this rise a pond six feet deep will develop about 4 H.P. per acre.

There is another way of harnessing the rise and fall of the tides by using floats and transmitting the power ashore. The weak point of this method is easily seen by figuring the energy of a falling weight. For the development of 100 H.P. with a 6-foot tide it would be necessary to have a float weighing 100,000 tons. The *Queen Mary* and the *Normandie* combined into one float would produce less than 200 H.P.!

Allied in principle to the tide motors are devices operated by the rise and fall of floats or buoys due to wave motion. It is doubtful if either of these latter types of power plants will ever come into general use. On a large scale they would generally require capital investment incommensurate with the power return. There are, however, certain spots, notably the Bay of Fundy on the east coast of Canada, where the natural configuration lends itself to such a project. The tidal rise here is almost 40 feet, and daily millions of possible horse-power hours run to waste. By building a sea-wall three miles in length across the narrow gap of two of its headlands, this power might be utilized. Such an engineering project would try man to his utmost and tax the resources of a nation, but the return would be a yield of power a hundred times greater than that of Niagara.

It will be seen from what has been said that gravity is really the ultimate force used in tidal machines. To be sure, it is the force of gravitation which causes the rise of the tide to fill the tidal ponds, but gravity is the force which later causes the water thus stored to fall again through a water-wheel. Our greatest use of gravity alone as a force in the development of power is in the utilization of the energy of falling water. With dams we are able to regulate the flow of brooks and rivers, make storage basins, and provide a water level from which the fall of water to a turbine wheel may be used to generate electricity. The hydro-electric stations already in operation, most notably the monster plants at Niagara, have barely touched the untold power which is now flowing daily to waste in our rivers and falls. Regulation of flow in rivers will secure a continuous average yield of power which can be maintained over long periods, even with diminished rainfall. At present some water-powers are useless at certain seasons due to low water. By damming and reduction of flow, these can be made to operate continuously. If water-power is developed in the United States there will be no trouble whatever in getting 300,000,000 H.P. with no use of fuel whatever!



LONG LAKE STATION OF THE WASHINGTON WATER POWER CO. OF SPOKANE
70,000 horse-power is developed.

Developed water-power resources in the United States in 1937 were rated at more than 17,000,000 H.P. We have hardly begun to tap our reserves of this sun-endowed store of energy.

It has been proposed that national forest lands in the United States be leased for a term of years for the production of water supply by private corporations, subject to government regulation. Many people favor government ownership of natural resources At present private power plants at night only, cities for hundreds of miles around could be supplied with electricity for lighting. The millions thus benefited would offset the hundreds who could no longer view the falls by moonlight.

Many potential water-power sites have been either destroyed or crippled by the ruthless cutting of timber on the watersheds adjacent to the fall. They assume the aspect of miniature Niagaras during a heavy rainfall, only to present a mass

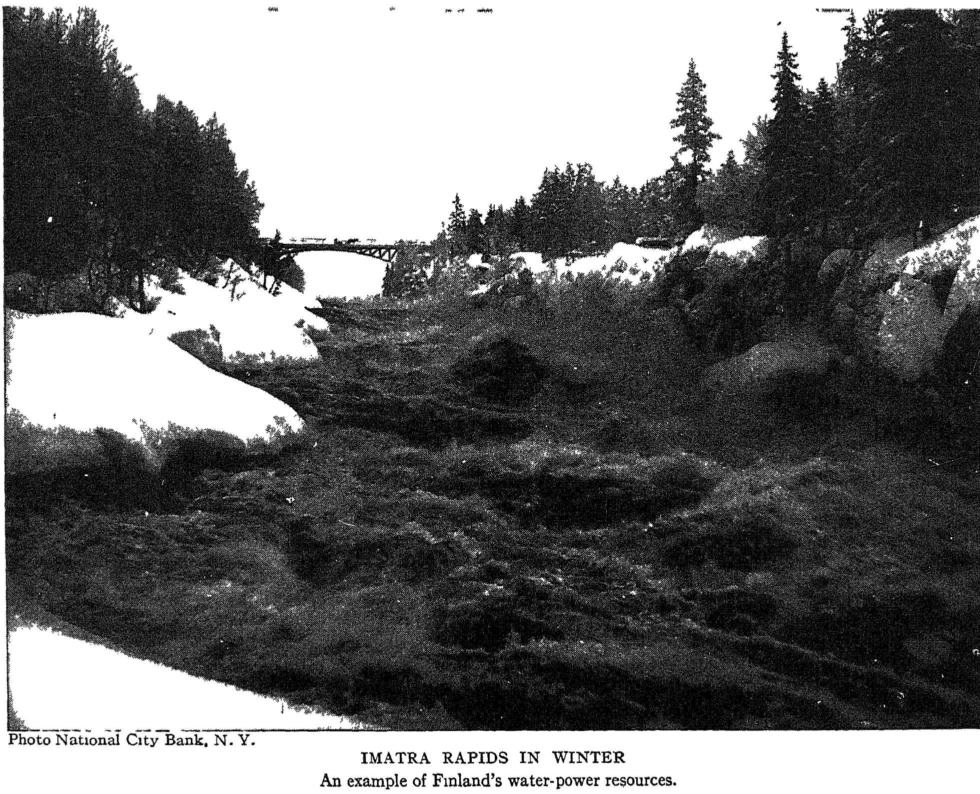


Photo National City Bank, N. Y.

IMATRA RAPIDS IN WINTER
An example of Finland's water-power resources.

interests are impeding, and probably will continue to obstruct government control, but undoubtedly the final outcome will be such control, and possibly operation.

One of the greatest water-powers of the world, Niagara, is limited in its possibilities by sentiment. To be sure, these falls are sublime in their grandeur, and it would seem a shame to destroy their beauty by drawing off the river by flumes to the extent of cutting off all flow over the falls. However, this is unnecessary; by increasing the amount of water used by the of dry rocks on the following day. Such practices must be stopped, and the government must protect the watersheds if the millions of possible water horse-power are to be saved for either our own use or for that of the coming generations.

The strongest recommendation of water-power is in its replacement. Coal and oil once burned are gone forever. Man cannot replace them, and nature's creation is a process of millions of years. Water, after doing its work, reappears again on reaching the sea by way of the clouds and rainfall.

There are two other promising sources of fuel worth mentioning: these are vegetation and the oil-bearing rocks of Scotland, Canada, the United States, Australia and the Yugoslavian state of Serbia.

Alcohol made from potatoes, beets, sawdust and cereals may have to be used for internal-combustion engines instead of the petroleum distillates. It has been claimed that it can be produced at a cost of 5 to 10 cents per gallon. In Germany before World War I it was sold as low as 15 cents per gallon. Alcohol for use in internal-combustion engines has some disadvantages; if pure, the engine must be started with gasoline. Addition of 10 parts of gasoline, however, is sufficient in warm weather. The compression pressure for alcohol is increased to 180 pounds per square inch, as against 50 to 90 for gasoline. This means that the cylinder walls must be very much stronger and probably heavier, for the maximum pressure is over 500 pounds per square inch as against 300 pounds for gasoline — a significant difference.

Advantages in using alcohol as fuel

The advantages on the side of alcohol are the smaller carbon deposits in the cylinder and elimination of obnoxious odors in the exhaust. For engines of the same size nearly 30 per cent more power for alcohol using 180 pounds compression pressure can be obtained at the same volume rate of fuel use. For the same power, this would mean greater fuel-carrying capacity for automobiles.

In considering the depletion of oil-well supplies, we must remember that oil-bearing shales are a source of petroleum that will furnish millions upon millions of barrels. These oil shales are found in several parts of the world, notably in Scotland, which supplies part of the British Navy's demand, and in the western part of the United States.

Oil is obtained from rock by distillation. A small amount may actually be squeezed out of the rock by pressure, but large amounts, from 40 to 90 gallons per ton of rock, are obtained by heating the rock and distilling the vapors driven off. Besides oil the process yields as a by-product ammonium sulfate, used for fertilizer. Scottish shales produce about 18 per cent oil and 2 per cent fertilizer, while the American shales yield 40 per cent oil and 6 per cent fertilizer. Furthermore, the American shales are more accessible by far than the Scottish, which are below the surface and require mining.

There are in North Dakota and Montana vast beds of lignite, sometimes called "brown coal." Lignite is coal in the making, and if subjected to pressure and heat for millions of years it would eventually become bituminous coal. Its heat value is about half that of the black coals in use today, but it does not hold together and cannot be burned under a boiler with the ease and advantage of the denser fuels. However, tests have shown that for gas-producer use it serves the purpose admirably. We may expect, then, that engines driven by gas from lignite fuel gas producers will utilize this source of fuel, which is abundant. Even excluding Alaska from our calculations, there are 740,000,000,000 tons available in the United States, one-third of which is on public lands.

Atomic energy as a new source of power

Undoubtedly there are in the universe forces as yet undeveloped by man that may some day be brought to work for him. The atomic energy in all matter is one of these, and already it has been utilized as an explosive and in biological and medical research. Also it is seriously considered as a source of power in industry and transportation, and experiments have been carried out along these lines. Notwithstanding these possibilities, conservation of natural fuels by eliminating wastes and improving utilization is still a prime necessity. Also our water powers must be conserved and protected, by rigorous government control if necessary, for unless new sources of energy are fully exploited, water must become, by development, one of the main reservoirs of energy for the power generation of the future, which will have to meet the demands of expanding world industry.

BETWIXT-AND-BETWEEN PARTICLES

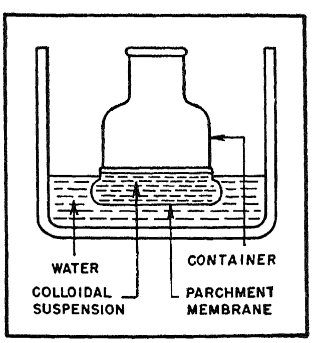
The Importance of Colloids in the World of Today

THE infinitely numerous objects that make up what we call matter fall roughly into three main divisions on the basis of size. On one hand we have the things that are large enough to be seen by the human eye, with or without the aid of an ordinary microscope — such widely differing forms as giant boulders and grains of salt, elephants and amoebae, oak trees and bacteria. At the other extreme there are molecules, the tiny building blocks of which all gases and liquids and many solids consist; atoms, which often combine to form molecules; ions, which are molecules or atoms with an electrical charge; subatomic (less-than-atom) particles, such as electrons, protons and neutrons. Finally there are a vast number of betwixt-and-between particles that are too small to be made out by an ordinary microscope and that are larger than molecules, atoms, ions or subatomic particles.

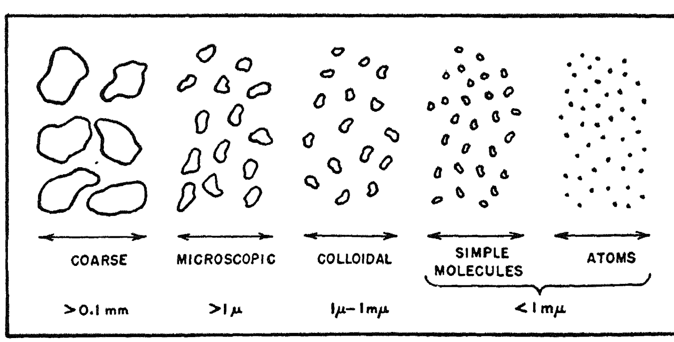
Until the nineteenth century these intermediate particles were unknown to man. One of the first scientists to pick up their trail was a Scotch chemist, Thomas Graham (1805–69), who was the master of the mint in London in the 1850's. In a paper that he published in 1861 in the PHILOSOPHICAL TRANSACTIONS, Graham pointed out that certain substances, like salt and sugar, can be readily dissolved and can be diffused (passed) through the pores of a parchment membrane immersed in water (Figure 1). He pointed out, too, that other dissolved substances, such as glue, gelatin and gums, passed through very slowly or not at all. He came to the conclusion that if a substance in solution (that is, dissolved in a liquid) had been reduced to its molecules or ions, it could diffuse readily, but that it could not do so if it were made up of clumps of molecules.

Since the materials that readily diffused when they were in solution all formed crystals when they became solids, Graham called them crystalloids. (See Index, under Crystals.) He gave the name of colloids, or gluelike materials, to the glue and the other substances that did not diffuse readily when in solution. (*Kolla* means "glue" in Greek.) Graham assumed that only the substances that he called colloids failed to diffuse readily.

In the years that followed, other chemists carried out researches on the colloids and discovered many new and interesting



1. Apparatus used by Thomas Graham to demonstrate the existence of colloidal substances.



2. How particles of matter are classified In the above diagram > stands for greater than; < for smaller than; mm for millimeter; μ for micron (1/1,000 mm); mμ for millimicron (1/1,000,000 mm).

Colloidal Particles	*Medium in Which the Colloidal Particles Are Scattered*	*Example*
Gas	Gas	This type of colloidal system cannot occur.
Gas	Liquid	Foams, froths; these are bubbles of air suspended in water.
Gas	Solid	Bubbles of gas, of colloidal dimensions, occurring in certain minerals, like meerschaum.
Liquid	Gas	Clouds, fogs, mists; these consist of water droplets suspended in air.
Liquid	Liquid	Emulsions: dispersions of fine particles of a liquid in another liquid.
Liquid	Solid	Liquid droplets in minerals, like opal.
Solid	Gas	Smokes and dust, consisting of solid particles suspended in air.
Solid	Liquid	Finely divided metals suspended in liquids.
Solid	Solid	Finely divided gold in ruby glass.

facts about them. Yet for a long time colloidal phenomena were considered to be a scientific curiosity, with little or no practical application; only a few specialists devoted themselves to the subject. When the eminent German chemist Wolfgang Ostwald wrote a book on the colloids in 1915, he ruefully gave it the title of THE WORLD OF NEGLECTED DIMENSIONS.

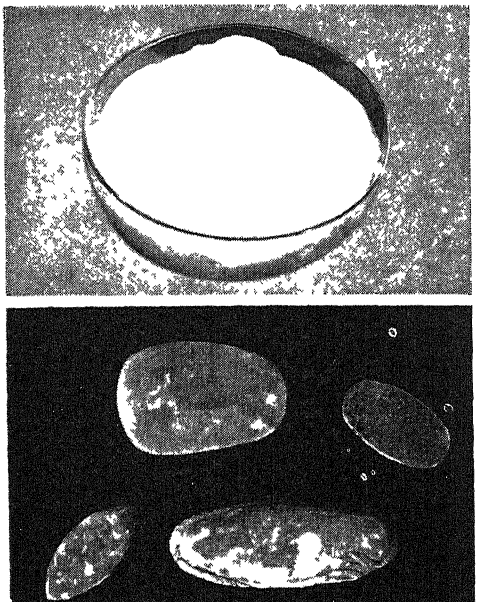
Today, all that has changed. We now realize that, to quote Ostwald, "colloids constitute the most universal and the commonest things that we know. We need only look at the sky, the earth or ourselves to discover colloids or substances that are closely related to them." We realize, too, that colloidal phenomena are exceedingly important, that they hold the key to many scientific riddles, and that they have an astonishingly wide practical application in many fields.

A distinct branch of science, called colloid science, is now devoted to the study of colloids. The colloid scientist is concerned with the composition and the properties of colloidal particles and the substances in which they are to be found. He examines the colloidal properties of the materials used in industry; he uses the knowledge that he has gained to create new industrial products and to improve old ones. Let us examine his findings.

Today the word "colloid" has a wider meaning than it had in Graham's day. It is applied to any material containing particles that fall within a certain range of dimensions and that are scattered throughout a certain medium.

Colloid scientists have noted that the smallest dimension that can be made out with an ordinary microscope is 1/1,000 of a millimeter, or 1 micron (written μ). The largest molecules that can pass readily through a parchment membrane are roughly 1/1,000,000 of a millimeter, or 1 millimicron (written $m\mu$), in size. Hence these two dimensions — 1 micron and 1 millimicron — have been established as the limits within which colloidal particles are to be found (Figure 2). Certain particles that do not fall within this range of dimensions interest the colloid scientist because they display various colloidal properties.

Colloidal particles may be the grains of a solid, the bubbles of a gas or the droplets of a liquid. The disperse medium — the medium in which they are dispersed, or scattered — may be a solid, or a liquid or a gas. The table given at the top of this page shows the various possibilities.



General Foods Corp.; Am. Mus. of Nat. Hist.

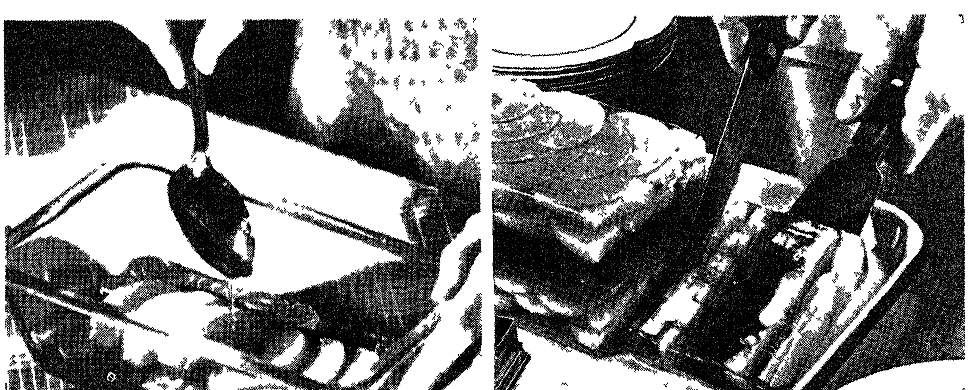
Two entirely different kinds of colloidal substances. Above whipped cream, below opals.

When colloids that are in solution present the appearance of a thin liquid, they are called sols. Under certain conditions sols can be transformed into substances of jellylike consistency, known as gels. The colloidal particles in gels are joined together to form a branchlike structure; the liquid is trapped in little pools within this structure. If gels are dehydrated, or dried out, they shrink considerably.

We pointed out, in the above table, that an emulsion consists of droplets of a liquid scattered in a liquid medium. Emulsions consist either of suspensions of oil in water (called o/w by colloid scientists) or suspensions of water in oil (w/o). Not all emulsions are of colloidal dimensions by any means; in many cases the droplets are quite coarse and may be examined by an ordinary microscope. However, even emulsions of this kind show many of the properties of colloids.

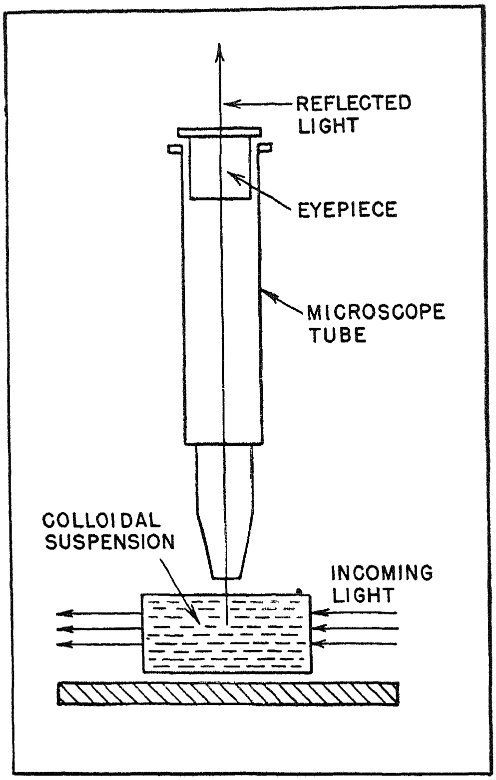
We can deduce the existence of colloidal particles, of course, from the fact that they do not diffuse readily through a parchment membrane. We can detect their presence in a medium because of a very interesting phenomenon known as the Tyndall effect, from the name of its discoverer, John Tyndall (1820–93), a British physicist. He passed a beam of light through a flask containing colloidal particles suspended in a liquid medium; the path of the beam in the liquid was clearly outlined because of the light scattered from the tiny colloidal particles.

H. Siedentopf and R. Zsigmondy made use of the Tyndall effect in the ultramicroscope, which they developed in 1903. This instrument made it possible to determine the position of individual colloidal particles within a suspension. The ultramicroscope (Figure 3) utilizes a high-power microscope. A powerful beam of light, at right angles to the line of vision



Jell-O Co.

The jelly pudding-to-be at the left is in liquid form; it is an excellent example of a colloidal sol. The pudding at the right has set to jellylike consistency; it has become a typical colloidal gel.



3. Diagram of ultramicroscope. A beam of light illuminates a definite area in a colloidal suspension, a microscope is focused on this area.

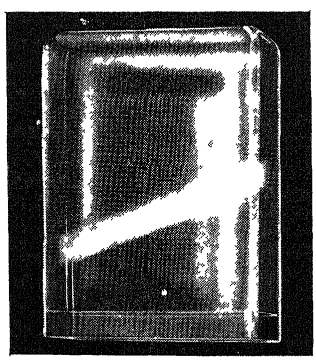
of the microscope, is focused upon a definite area in a colloidal suspension under the microscope. The microscope is then focused upon this area in the suspension. The viewer sees, not the individual colloidal particles themselves, but the light that is scattered by each particle in the medium.

Colloidal particles have a vast amount of surface compared to their mass. We can illustrate this point by systematically cutting up a cube of any substance with an edge-length of 1 centimeter. The cube that we begin with has 12 edges, each of them 1 centimeter in length; it has 8 corner points; it has a total surface area of 6 square centimeters; its volume is 1 cubic centimeter. First we cut this cube into slices, each 0.5 micron or 500 millimicrons thick (A in Figure 4); this is the halfway mark of the colloidal range of dimensions. Next we split these sheets into rods, each 500 millimicrons wide (B in Figure 4); finally we subdivide these rods into cubes, each with an edge length of 500 millimicrons (C in Figure 4).

We have now produced the amazing number of 8,000,000,000,000 cubes, with a total of 96,000,000,000,000 edges and 64,000,000,000,000 corner points. The over-all surface area of these cubes reaches the total of 120,000 square centimeters; there is exactly 20,000 times more surface now than when the substance was in the form of a single cube. Yet the combined volume of all these tiny cubes is the same as that of the single cube with which we started — exactly 1 cubic centimeter!

The tremendous amount of surface of colloidal particles has important consequences. For one thing it hastens the completion of chemical reactions, since the speed of such reactions depends partly on the surface area offered by the reacting substances. (See the article on Chemical Reactions, in Volume 2.)

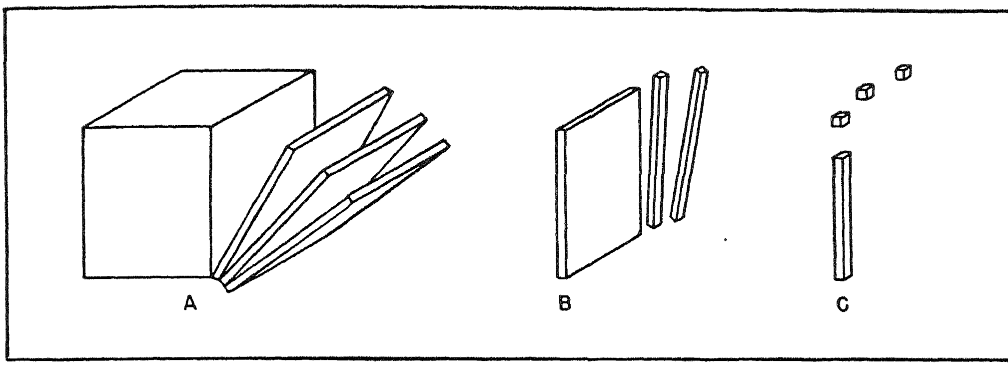
Particles of colloidal size have a greatly



The path of light in this colloidal suspension is like the path of sunlight that is revealed by dust motes in the air.

From Elements of Chemistry, publ. by Allyn Bacon

increased tendency to hold molecules and ions of other substances to their surfaces because of the forces of attraction. Let us see why this is so. Figure 5 shows a cross section of a silver bromide crystal, in which positive ions of silver (Ag^+) and negative ions of bromine (Br^-) alternate. Silver ion 1 is fully balanced by four bromine ions; it is saturated — that is, it holds to itself all the particles that it is capable of holding. Silver ion 2, located on the edge of the crystal, is one bromine ion short of saturation; silver ion 3 is two



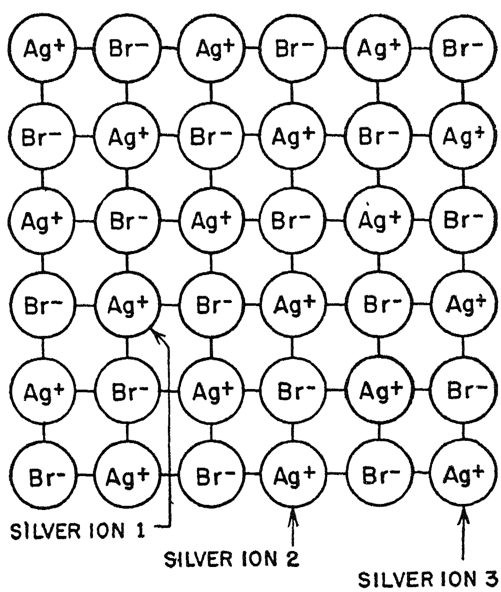
4. When a cube of any substance is sliced, split and cut into cubes, as shown in the above diagram, there is many times as much surface as there was when the substance was in the form of a single cube.

bromine ions short of saturation. Therefore ions 2 and 3 will eagerly reach out for any stray ions that happen to be in the vicinity.

The smaller the crystal, the more corners and edges there will be in proportion to its mass and the more the crystal will attract ions or molecules. This tendency of a substance to hold particles of other substances to its surface is called adsorption. According to a theory proposed by a great American chemist, Irving Langmuir, substances adsorbed in this way form a layer only one molecule or one ion thick.

We can show how adsorption works by means of a very simple experiment. Let us divide a piece of charcoal into two pieces of approximately the same weight. We leave one piece intact; we grind the other to as fine a powder as possible. We now make a strong water solution of a dye such as methylene blue or crystal violet, and we place equal quantities of the solution in two glasses. We put the piece of charcoal in one glass and the finely divided charcoal powder in the other. We stir the contents of the glasses well; then we filter the contents of each glass, in turn, through a dense filter paper. The dye solution in the glass containing the single piece of charcoal will come through the filter paper without any appreciable change in color. But the liquid that comes through the filter from the glass containing the charcoal powder will be colorless. The powdered charcoal has adsorbed the particles of dyestuff contained in the dye solution.

What causes the particles in a colloidal suspension to remain dispersed throughout the medium instead of precipitating, or settling out? One reason is that they are constantly bumping into one another as the result of a random, zigzag motion that is called the Brownian movement. It is named after the Scotch scientist Robert Brown (1773–1858), who first observed it while studying pollen suspended in a liquid. Brown was mystified by the erratic wanderings of the pollen particles; but



5. Cross section of a silver-bromide crystal, in which positive silver ions (Ag^+) alternate with negative bromine ions (Br^-). Silver ion 1 is saturated; silver ion 2 is one ion short of saturation; silver ion 3 is two ions short of saturation.

modern science has provided an explanation. The particles move because they are being constantly bombarded by the molecules of the medium. As we saw in the article on How Molecules Behave, in Volume 1, molecules are constantly in motion except at the temperature that is called absolute zero ($-273°$ centigrade, or about $-459°$ Fahrenheit).

In a typical colloidal suspension, particle A, let us say, is about to yield to the force of gravity and drop to the bottom of the container holding the suspension. Suddenly it is struck by particle B and is deflected from its downward course. As it moves toward the side of the container, it is struck from below by particle C; no sooner has it veered upward when particle D strikes it from above. The kinetic energy (energy of motion) of the individual molecules is so small that it would have little effect on particles appreciably larger than those of colloidal size; such larger particles would sink to the bottom of the container.

Electrical forces also play a part in keeping colloidal particles suspended in their medium. Particles in solution have an electrical charge, which they have picked up by adsorbing ions present in all solutions. All the particles in a given suspension have the same charge; therefore they repel one another. The result is that they do not merge to form larger particles, which would not be affected so much by the Brownian movement and therefore would settle more readily.

Colloidal particles occurring in emulsions are kept from precipitating by adsorbing other particles, which are called protective colloids, or emulsifying agents. These protective colloids concentrate in the interface (boundary) between the liquid of the colloidal particle and the liquid in which it is suspended. They form a membrane around each droplet; they thus prevent the droplets from merging and becoming so large that they will precipitate.

For example, when oil droplets are suspended in a vinegar medium, the two liquids soon separate. The oil is all collected in one layer; the vinegar in another. To make mayonnaise dressing, an emulsifying agent, the protective colloid known as egg yolk, is added; the oil droplets then remain permanently suspended in the vinegar medium.

Many of the colors that we see around us are due to the scattering of light from colloidal particles. The particular colors depend on the size of the particles, their texture and the direction in which they are oriented, or turned. The color of certain bird feathers results from such scattering of light. In these feathers a great many air bubbles of colloidal size are suspended in a solid medium. These bubbles scatter blue light but transmit red light, which is absorbed by the dark background formed by the body of the bird. As a result, the feathers appear to be blue.

How chemists produce particles of colloidal dimensions

In bringing about various desired chemical reactions, chemists often have occasion to produce particles of colloidal dimensions. They can do so in several ways. They can break down comparatively coarse particles into particles of colloidal size; this is called peptization, from the Greek word *peptein,* meaning "to digest." The simplest way to peptize materials is to grind them in a special kind of mill, called a colloid mill. If coarse particles are held together by weak molecular forces, they can be broken up into smaller particles by putting them in a liquid for which the particles have great affinity — that is, to which they are strongly attracted. Thus latex particles can be reduced to colloidal dimensions if they are immersed in benzene.

The chemist can also produce particles of colloidal size by building up smaller particles until they reach the colloidal range of dimensions. Substances that have been reduced to their molecules or ions in a solution can be made, under certain conditions, to form tiny crystals of colloidal size.

Colloidal particles do not always remain in suspension. If electrically charged particles lose their charge, they will no longer repel one another; they will gradually

merge and then precipitate. This is true of colloidal particles in liquid and gaseous mediums alike. Thus, if a solution containing ions with a positive charge is added to a colloidal solution in which the particles have a negative charge, the positive ions will seek out the negative ones and the charge on the latter will be neutralized.

If an electric field is set up in a colloidal suspension, the charged colloidal particles will move over to the electrode with the opposite charge. This is called electrophoresis. As the charged particles come in contact with the electrode, they lose their charge and precipitate.

In some cases charged colloidal particles cannot move to the electrode containing the opposite charge because they are felted, or interwoven, as in the case of clay pastes and peat. In that case, the water of the disperse medium can be made to move to the opposite pole through a porous diaphragm. This is called electroosmosis; it is often utilized to rid peat moss and many other natural products of their water content.

Such, then, are the colloids and the more important phenomena in which they play a part. These phenomena are involved in so many processes found in nature or prepared by man that it would take many volumes to deal adequately with them. Let us give a few examples.

Living processes are based on matter in colloidal form

All living processes are based on matter in the colloidal state. The cells of which living things consist are made up mainly of colloidal particles suspended in water. The rapid rate at which reactions occur within cells is due to the vast surface area offered by the colloidal particles. If these gather together in clusters and settle out in a cell, that cell dies.

Colloidal phenomena play an important part in digestion. For example, certain salts contained in bile act upon fat; they break it down into particles of colloidal size. This greatly increases the surface of the fat exposed to the enzymes that are secreted by the pancreas. As a consequence the fat is digested much more rapidly.

The clotting of the blood is a colloidal phenomenon. Colloid particles of a protein called fibrinogen are suspended in the fluid part of the blood. Ordinarily they form a sol. But when the blood vessel is injured or when blood escapes through a wound, the fibrinogen is transformed by special mechanisms within the body into a gel — a blood clot that helps to prevent loss of blood.

Muscles are a colloid gel; they may be compared to the gelatin, in gel form, that we eat for dessert. If you shake such gelatin too vigorously, it will gradually lose its water content and will shrink. If it is kept undisturbed, the gelatin will readsorb the water in time and will regain its original condition. Much the same thing happens in the case of our muscles. We constantly agitate them during the day, even if we do not engage in violent activity; as a result, they, too, are gradually dehydrated. With rest, however, they return to their former state.

Colloids in the world of inanimate nature

The colloids play an important part in the world of inanimate nature. They account, as we have seen, for much of the color that we see about us. The blue of the sky and the red of sunsets are both derived from the scattering of light from particles of dust in the atmosphere. (See the article on Dust in this volume.) The color of the iris of the eye, in some cases, depends on the way in which the colloidal particles are dispersed, or scattered. As you know, certain animals, like the chameleon, are able to adapt their color to their surroundings. They do so by altering the degree of dispersion of the colloidal particles in the skin.

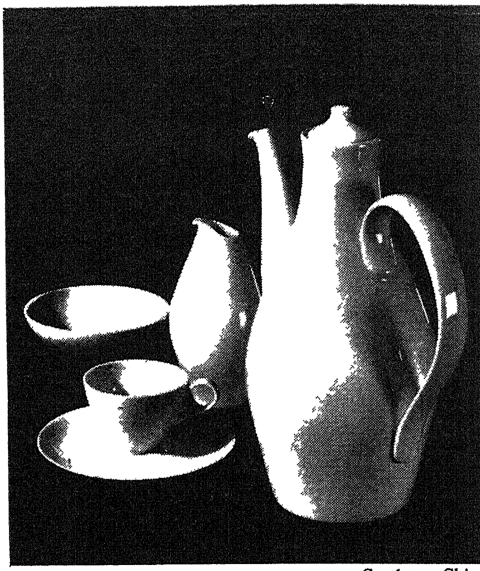
The formation of deltas at the mouths of rivers is a colloidal phenomenon. The silt of such rivers contains many coarse particles and also others of colloidal size. The coarse particles gradually settle out as the river flows along its course. The colloidal particles, however, remain in suspension,

as the current carries them along, since they have the same electrical charge and hence repel one another. The river now approaches the ocean. The salts dissolved in sea water consist of ions; as they come in contact with the colloidal particles in the river they neutralize the electric charge upon them. The particles no longer repel one another; they merge, and the large combined particles drop to the bottom of the river mouth. In time they give rise to vast delta systems, like those of the Nile and the Mississippi.

Foods offer a great many examples of colloidal phenomena; the curdling of milk is one of them. The particles of casein, a protein that occurs in milk, are negatively charged. When the sugar in milk ferments, lactic acid is produced; this contains positive hydrogen ions. The hydrogen ions are attracted to the negative particles of casein and the latter are neutralized. They no longer repel one another but coagulate, and thus curds are formed.

Sometimes we utilize colloidal phenomena to alter the nature of foods, as in the preparation of homogenized milk. In ordinary milk, the globules of fat that make up the cream are not colloidal particles; they are relatively coarse. They have a lower specific gravity than the water and the proteins contained in the milk. Therefore, if we let milk stand, the butterfat globules will rise and concentrate at the surface. To prevent this from taking place we break up the globules by squirting the milk under high pressure against a plate of agate or a hard metal disc or through a nozzle equipped with a special type of diaphragm. Each of the fat globules is broken up into a number of smaller ones of colloidal size. These become coated with the proteins in the milk, which concentrate at the interface and serve as protective colloids. The protein concentration, together with the Brownian movement, will prevent the globules of butterfat from flowing together as before.

In certain countries the proteins that are such a useful element of diet are not particularly abundant. Colloid science has made it possible to add to the supply. To



Castleton China

These exquisite specimens of the potter's art were all fashioned from a variety of clay. Clay is a good example of matter in the colloidal state.

recover proteins from the waste water that results from the production of potato starch, finely distributed air bubbles are passed through the liquid. The protein concentrates on the surface of the bubbles and rises with them to the top of the liquid. The bubbles form a foam, which is skimmed off. After drying, the proteins are ready for use.

Colloidal phenomena play an important part in a vast number of industrial processes. In many cases these go back hundreds or even thousands of years, but only since the development of colloid science have we been able to understand them. In other cases entire industries owe their rise to the development of colloid science.

The ceramic industry, devoted to the manufacture of pottery and tiles and similar articles of baked clay, draws its raw materials from various clays, which are a good example of matter in the colloidal state. All the clay particles have the same kind of electric charge and repel one another. Because they are so closely packed, they cannot move freely but maintain the same relative position. If a force is exerted upon the clay, the particles slip by each other, thus permitting the shaping of

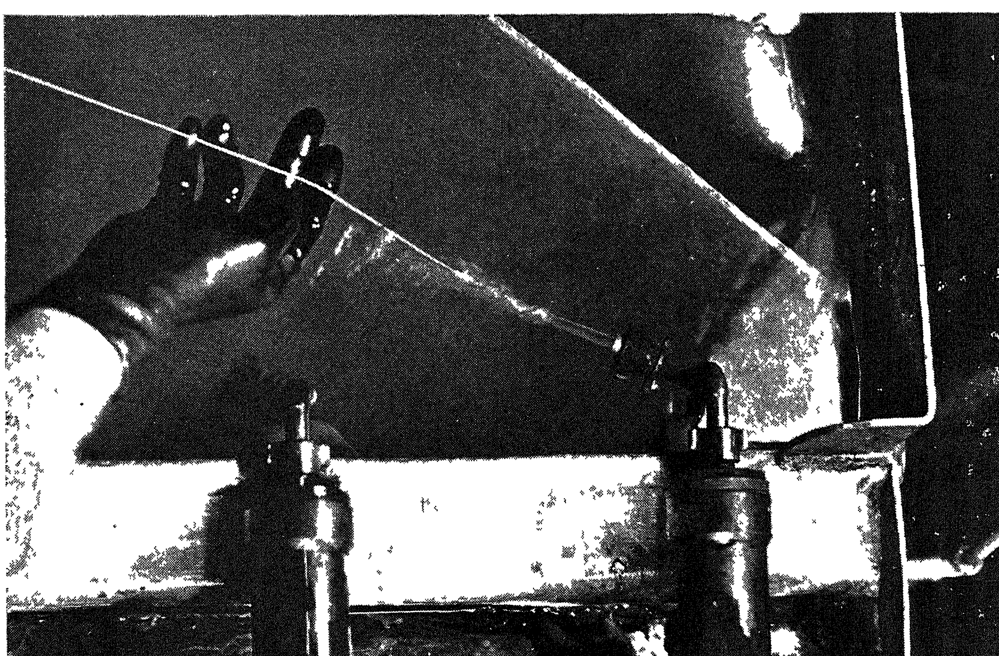
the vase or plate or other object that is being fashioned by the potter. When the force is removed, the particles retain their new position, since the same electrical forces as before act upon them.

The process of flotation, by which pure minerals are separated from their ores, involves particles of colloidal size. First, the ore is ground to a very fine dust and is mixed with water. A small amount of carefully selected oily material is then put into the water; this oil will be adsorbed only on the surface of the desired mineral particles. The mixture is now agitated and frothy suds are produced. As you know, oil is lighter than water. The oily part of the suds carries the mineral particles upward with it. The impure materials in the ore, which have not adsorbed any oil, remain at the bottom. The froth that has accumulated at the surface is then skimmed off, and the mineral is obtained in an almost pure condition.

The plastics industry is based chiefly upon colloidal phenomena. In the preparation of rayon, for example, cellulose, the framework of plants, is transformed into a colloidal sol by the use of appropriate solvents. It is then squirted through a spinneret into a coagulating bath and a thread of artificial fiber is produced.

The extensive soap and synthetic-detergent industry provides an excellent example of colloid particles at work. (See the article on Soaps and Synthetic Detergents, in Volume 10.) The paper industry is another example; sheet formation, coating, glossing and printing are based on the colloidal properties of cellulose fibers, glue and inks. The photographic industry utilizes gelatin and colloidal silver salts as the light-sensitive ingredient of the film or photographic plate.

Adsorption plays an important part in various industrial processes. Activated carbon provides a particularly good example of adsorption at work. This substance is obtained principally from charcoal by steaming or by treatment with various chemicals. The purpose of the processing in either case is to remove any impurities and thus to open up all the pores of the



Du Pont

From colloid to artificial fiber. A colloidal sol, derived from cellulose, is forced through the many fine holes of a spinneret into a coagulating bath and is transformed into a thread of rayon.

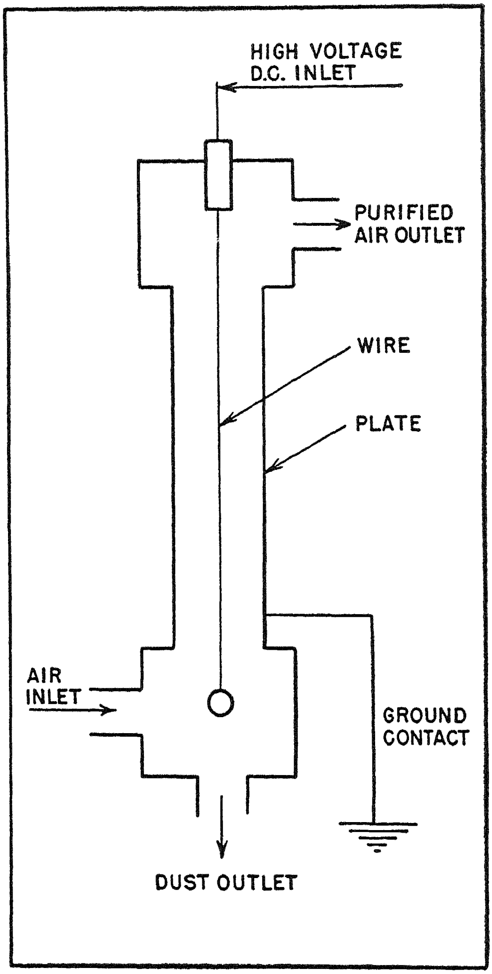


Diagram of a Lodge-Cottrell electrical precipitator. Smoke particles enter an electric field set up by current passing through the wire; they are charged. They are attracted to the plate, which has an opposite charge; after being dislodged from the plate they pass through the dust outlet.

substance. As a result there is a tremendous increase in the amount of exposed surface and in the number of unsaturated carbon atoms; the adsorbing capacity of the substance becomes much greater.

Activated carbon is used widely in industry for the recovery of volatile solvents — those which readily evaporate. The vapor is passed through a column or tower stacked with activated carbon, and the vapor particles are adsorbed on the surface. The saturated adsorber is now heated and the solvent that has concentrated upon its surface is removed. Activated carbon is also used in gas masks; poisonous gases are adsorbed on the surface of the carbon while the oxygen and nitrogen contained in the air pass through freely to the lungs.

Among the unfortunate by-products of industry is the smoke that escapes from the chimney flues of many manufacturing plants. Such smoke is always annoying and it may be extremely injurious to both animal and plant life. Fortunately colloid science has made it possible to deal with this nuisance.

In the first decade of the present century an American chemist, Frederick Gardner Cottrell, developed a device for precipitating by electrical means the particles contained in smoke. This device, which is called the Cottrell electrical precipitator, has been widely adopted. In one type of precipitator (Figure 6) there are a number of parallel plates, housed within a shell; these plates are set about a foot apart. Wires running parallel to the plates are set midway between them. The smoke that is to be treated enters the precipitator. A powerful electric charge passed through the wires causes an electric field to be set up; the particles in the smoke are then charged. Since the plates, which are in another circuit, have the opposite charge, they attract the charged particles, which collect upon the plates. The particles are dislodged from the plates by rapping or scraping, which is done either by hand or automatically. Then the particles drop into hoppers and are removed. The Cottrell process does away with bothersome fumes; furthermore, it recovers valuable materials, such as metallic oxides, which would otherwise pass out with the smoke to the outer air.

We could expand almost indefinitely this brief account of colloids and the part they play in the world about us. Already colloid science, a lusty infant among sciences, has revolutionized our ideas concerning living things and inanimate nature and has brought about advances in many fields of human activity. As the science matures, we may look forward to many other notable advances in the years to come.

THE REIGN OF THE GHOST

How the Fiercest of Primitive Races Came
To Respect Human Life and Property

THE ORIGIN OF FUNDAMENTAL LAWS

IN any kind of stable government there must be a respect for human life and a respect for property. The central authority, or the community at large, may possess all the property, and may exercise a tyrannical power over the lives of the people; yet the individual member of society must not rob or slay his neighbors. All this is obvious; but the origin of the ideas of ownership and of the sanctity of human life is very far from being obvious. The matter was not plain when Herbert Spencer completed his masterly survey of the evolution of human society, and it is only within the last few years that our younger leaders of science have been able to throw a strange and yet clear light on it.

It is believed by many anthropologists that the art of government was developed by a class of magicians who ruled by superstitious fears and practices. Brute force did not play in the early forms of society so important a part as is commonly thought. For we have found in tracing the origin of kingship that superstition has often been more potent than reason or armed ambition in building tribes into nations.

And what we now aim at showing is that superstition has often done more than laws or material punishments to establish in the mind of primitive and savage man that respect for human life and for private ownership without which the world would have been ruled by successful murderers and thieves. It is patent that the more violent instincts of uncivilized man had first to be repressed, before anything larger than the family clan came into existence. But it is not easy to see at a glance what power there was available to this end.

Primitive and savage men have at times even hunted their fellow-creatures for food; and there was no constraining force outside of their individual selves which could repel them from murder and robbery. Indeed, it must have been the easiest thing in the world to find an opportunity for slaying even a relative out of anger or jealousy or ambition. The ancient hunters were often brave and daring men, who risked their lives almost daily in the pursuit of game. Some of them, even in the Old Stone Age, were the practical masters of the earth, and the huge and ferocious cave-bear was their favorite food. Men such as these had to be forced to respect each other's persons in the wildest outbursts of bad temper, while living under conditions of great hardship with practically no social machinery to enforce the respect for human life.

As a matter of fact, the work now done by our highly organized police system was then performed by the murdered man himself. It may have been a dangerously facile thing to kill his body, but that only set his ghost free to haunt the slayer. Primitive man certainly believed in ghosts, and he seems to have had the same superstitions concerning them as the modern savage. Beside the body of his dead he placed a store of food and an armory of weapons for use in the spirit land. He believed that animals had spirits as well as men, for he has also left, in the caves in which he dwelt, pictures and carvings of the beasts he hunted. They are apparently drawn for magical purposes, one representing men disguised as animals going through some strange ceremony.

The impressionable and unsettled state of the minds of savages

A great deal of evidence of this sort has lately been discovered among the most ancient of the existing remains of early men. It all goes to show that primitive man had much in common with the modern savage in the matter of beliefs. At one time it used to be argued that no just conclusions with reference to the evolution of human society could be drawn from the study of existing savage races. It was contended that the modern savage had very likely developed in a direction entirely different from that of the chief primitive tribes of prehistoric times.

It is highly probable that some of the customs and beliefs of modern savages are more complicated than those of primitive men, but, on the other hand, there are many indications that the savage has preserved the main lines of very ancient ways of thinking and feeling. His mind is almost as much a relic of the Age of Stone as the flint weapons he uses in hunting and warfare. Moreover, we are often able to discover, in the traditions of the most civilized of present nations, vestiges of prehistoric institutions which can only be understood when they are compared with forms of government still obtaining among savages.

Now, in regard to the origin of the idea of the sanctity of human life, we must remember that the savage imagination is very impressionable and remarkably childish. Everything that a man of the lower races does not clearly understand frightens him, and there is very little that he really does understand. There are good grounds for assuming that he is amazingly susceptible to hypnotic suggestion. Many savages can actually be killed by witchcraft. If they learn that the customary magical rites for destroying them have been performed, they will become ill and die — simply through their wildly extravagant and imaginary fears. This psychological fact has more bearing on the origin of certain human laws than have all the theories about social contracts and myths concerning the earliest legislators.

Modern sentiment about ghosts a survival from the terror of earlier times

Greater than the fear of the living magician is the dread of the ghost of a dead person. To the savage way of thinking, the soul of a baby that dies soon after birth may become a very harmful spirit, continually haunting the whole tribe, and bringing disaster upon all its undertakings. The fear of ghosts is hardly extinct among ourselves, and it is practically universal among savage people. All ghosts are dreaded, but the spirits of slain men are especially an object of terror to their slayers and to the community.

In ancient Greece, even an involuntary homicide was exiled for a year, so that the anger of the wraith of the dead man should have time to cool down. Orestes, the son of Agamemnon, killed his mother because she enticed her husband to a bath on his return from Troy, and there had him slain by her paramour. Orestes' act was an act of justice, but according to the Greek view it did not save him from punishment. The ghost of his mother pursued him wherever he went, and at last maddened him. In this wild and tragic legend is faithfully reflected the ancient Greek conception of the fate which overtakes the murderer at the hands of the ghost.

Homicides banished to protect community from visitation by the spirit of the dead

It was more in self-defense than out of any consideration for the slayer that a Greek community compelled him to depart from the country. This is evident from the provisions of the law. In the first place, the homicide had to keep to a certain road when going into banishment. It would have been hazardous to let him stray about the land with an angry and dangerous spirit dogging his steps. In the second place, if another charge was brought against a banished man-slayer, he was allowed to return and plead in his defense. He was not, however, allowed to set foot on land. He had to speak from a ship which was not permitted to anchor, and the judges decided the case while sitting or standing on the shore.

The ghostly revenges feared from murdered men by savage people

Obviously, the intention of this rule was literally to insulate the slayer, lest by touching the earth, even indirectly through the anchor or the gangway, he should blight everything by a kind of electric shock. The ghost-ridden man was full of a sort of effluence of death, and any contact with him might kill the crops or spread some plague.

Seeing that the most intelligent and cultivated race of the ancient world, the Athenians, were governed in their respect for human life by superstition, we cannot wonder that many savage and barbarian peoples are still obsessed by similar ideas. Among the Omaha Indians a murderer whose life was spared by the kinsmen of his victim had to observe certain rules for two to four years. He had to walk barefooted, and never eat warm food, nor speak loudly, nor look around him. He had to tie his robe tightly about him, and keep his hands always close to his body. Even if his hair was free, the ghost might get hold of it. Nobody would eat with him; and when the tribe went hunting, he was compelled to pitch his tent a quarter of a mile from the rest of the people, lest the ghost should raise a high wind which might cause damage.

When the spirit of a murdered man is thus feared by everybody, it is natural it should be especially dreaded by those against whom it may be conceived to bear a grudge. For example, when the relatives of a murdered man among the Yabim of New Guinea accept compensation instead of avenging his death, they must get one of their family to mark them with chalk on the forehead. If this is not done, their dead kinsman is sure to punish them for not avenging him. Perhaps they will suffer from toothache, and end by losing all their teeth, or the ghost will frighten and drive away all their pigs!

Practically everybody in a savage community who dies a violent death becomes a public danger. The temper of the ghost is naturally soured, and it is ready to avenge itself on the first person it meets. It is too angry to discriminate between the innocent and the guilty. So general offerings of food are made to the spirit by the tribe, in the hope of propitiating it.

Laying the ghosts of slain men by blood-stained ritual

In some places, however, an attempt is made to frighten the ghost away. Papuan villagers assemble for some nights after a murder has been committed, and beat drums and shriek to drive away the spirit of the dead man. Many Indian, Zulu and Fijian tribes take similar measures to protect the community against the angry ghost. The Bhotias of the Himalayas perform an elaborate ceremony for transferring the spirit of the dead man to an animal, which is beaten by all the villagers and driven away. Having thus expelled the ghost, the people return with songs and dances to their village.

The shedding of blood can often be expiated by some magical rite. This usually consists in sacrificing some animal, presumably to the ghost, and washing the slayer in its blood. The Greek mode of purifying a homicide was to kill a sucking pig, and wash in its blood the hands of the guilty man.

The penitence and purification of the victors in savage warfare

The Cameroon negroes smear all the relatives of the slayer and the slain with the gore of an animal; and practically all savage races perform some ceremony or act to lay the ghosts of slain men. Of course, men killed in battle are just as dangerous spirits as men murdered in the ordinary way. Something has always to be done to evade the terrible results of a victory, or the souls of the defeated host will sweep down and destroy by magic their conquerers. The methods adopted in the defense against the spirits of the slain are too numerous, and often too ghastly, to be fully related here. Acts of penitence lasting for six months are performed by some Indians; the Basutos wash themselves in running water with the help of a magician, and follow this with the sacrifice of an ox.

Several tribes in various parts of the world shave their heads, a custom which the ancient Greeks at one time followed. Many savage warriors shut themselves up in their huts, and their wives and friends shun them. Others live for a time a hermit's life in the forest, being exiled just as Orestes was, so as to concentrate the malignity of the ghost on themselves, and prevent it from attacking the whole community. Some Australian natives, on returning home from a victory, turn when their camp is in sight and perform an excited war-dance. This is really a fight with the spirits of the slain men; and the warriors fancy they can tell by the sound made by their shields whether they have defeated the ghost, or whether the ghost has struck them a mortal wound from which they will soon die. Professor J. G. Frazer has collected a vast store of practices of this kind, which will be found, by readers interested in the subject, in his book "The Golden Bough".

How dread of ghosts tends to preserve life in overcrowded China

Nowhere is the fear of ghosts so salutary an influence in enforcing a respect for human life as in the vast commonwealth of China. As is fairly well known, when a Chinaman is suffering under a grievous wrong, he will often commit suicide and convert himself into an angry ghost, in order to wreak in death that vengeance on his oppressor which he could not exact in life. In another way the general welfare of the Chinese race is promoted by the dread of ghosts. Life is so hard in many parts of the country that married peasants are often strongly tempted to restrict the size of their families by female infanticide. It is the fear that the souls of the murdered little ones will gruesomely punish the parents which prevents the Chinese farming classes from unnaturally restricting the growth of population.

So, finding that superstition has originally done more than any system of laws to keep men from shedding each other's blood, we shall not be surprised to discover that it has also clearly helped to maintain the respect for private property.

As even animals of intelligence display a sense of proprietorship, the old theory that individual property was not recognized by primitive men seems to be contrary to fact. When we see that the claim to exclusive possession is understood by a dog, so that he fights in defense of his master's clothes left in his charge, it becomes impossible to suppose that mankind in its very lowest state was devoid of the ideas and emotions that give rise to private ownership.

The use of ghostly fears in the preservation of private property

On the other hand, private property in land is very unusual among savage tribes. The hunting-ground is held in common, and when the hunters develop into farmers the tradition of communal ownership often grows more strong and binding. The tribe depends so much on cooperation in both warfare and agriculture that its territory usually remains a great common possession, binding all the members together. It is to the fruits of individual industry that the sense of private ownership appears first to attach. The problem which the savage has first to solve is to prevent other persons from stealing the weapons and instruments which he has slowly and laboriously fashioned. A Bushman, for instance, sometimes picks up the arrows lost by another hunter in the chase. It would seem natural in the circumstances for him to profit by his find, for he would thereby be saved the trouble of arrow-making. As a rule, however, the Bushman is at pains to return the lost objects to the rightful owner. "How do you know to whom the arrows belong?" a Bushman was asked. He pointed to some marks on the shaft.

Marks and designs of a similar kind are found on weapons of the Old Stone Age in Europe, and it is fair to assume they were made for the same purpose, probably of a magical nature. Every savage regards himself as something of a magician; he may not have those powers which are possessed by the chief wizard of the tribe, but he is confident that he can protect his private belongings.

Beneficial action of the taboo superstition in preserving individual belongings

This is done by a magical rite, which has various names. In Polynesia it is known as *tapu;* in Melanesia the system is known as *tambu;* in the Malay Archipelago it is commonly termed *pomali;* and in Madagascar it is called *fady*. The rite is widely practised in Africa, and it has been imported by negroes to the West Indies; it also obtains at the present time among native tribes of America, and in many other parts of the world. The South Sea term for it has been naturalized among us as "taboo", but as used by us this word does not convey fully the original meaning, nor have the same significance.

In the opinion of the natives, the effect of tabooing a thing is to endow it with magical energy which renders it very dangerous to anybody except the rightful owner. Before the natives came into contact with Europeans, the system of taboo worked with amazing success. The most valuable articles might, in ordinary circumstances, be left for any length of time to its protection, in the absence of the owner, without fear of being molested by any of the other members of the tribe.

If anyone wished to preserve his clothes his house, his crop, or anything else, he had only to taboo the property, and it was safe. To show that the thing was tabooed, he put a mark on it. Thus, if he wished to use a particular tree in the forest to make a canoe, he tied a wisp of grass to the trunk; if he left his house, with all its valuables, to take care of itself, he secured the door with a piece of flax. The place at once became charged with a sort of curse, ready to fall on any interferer. It meant at least a very bad sickness.

Moreover, the curse could be made retrospective. If a man went to his plantation, and saw that some cocoanuts had been stolen, he ran about shouting imprecations on the thief. As the thief believed in the magical effect of the curse, it naturally troubled him, and worked on his highly impressionable imagination. Men and women have been known to fall dead on learning that, merely by mistake, they had eaten some food which had been previously tabooed by their chief. This astonishing susceptibility to hypnotic suggestion is a characteristic of many of the lower races which must always be kept in mind when studying their apparently foolish institutions.

A MEDICINE-MAN IN CENTRAL AFRICA

The patient is lying on a mat in the sun, the medicine is in the waterbuck's horn resting on the injured hip, the medicine-man is decorated with white pigment, and by his gymnastic exercises is supposed to be chasing away the disease
Reproduced by permission from Mr Alfred J Swan's book, "Fighting the Slave Hunters in Central Africa", published by Seeley & Co

The means by which these institutions are worked seem childish and foolish because they are connected with a condition of mind away from which many — but not all — members of highly civilized communities have now developed.

The hard, clear reasoning power which is the priceless possession of the highest races has enabled the best minds among them to escape from that extravagant power of non-rational suggestion which was called into play by the primitive chief to control the individual members of his tribe.

The importance of savage susceptibility to hypnotic suggestion

They have lost, perhaps, the responsiveness to suggestion on which mental healers rely, but this loss is more than compensated by a gain in self-control and concentrated reasoning power, which is one of the greatest of all the forces in modern civilization.

To understand the savage and the primitive man, we must attempt to see things from their strange point of view. We must admit that witchcraft can be efficacious when it is used on persons extremely liable to hypnotic suggestion. When we have admitted this, we shall perhaps see that black magic was not altogether a malign and misdirected force in the earliest stages of the evolution of human societies. We are not concerned to maintain that the general good effects procured by the various forms of witchcraft were sufficient to outbalance the numerous and long-enduring bad effects.

The system of taboo kept primitive man in an organized state of society

Millions on millions of human lives have been destroyed in the course of the ages through superstition. Yet we must not allow our feelings of disgust to blind us to the fact that the strange, unreasonable and impressionable mind of primitive man has sometimes turned to good use the forces of evil that worked in it.

"The New Zealanders," said A. S. Thomson, in 1859, "could not have been governed without some code of laws similar to the taboo." Warriors submitted to the fear of magic who would have spurned with contempt the orders of men. It was certainly better, having regard to the absence of law and the fierce character of the people, that they should be ruled by superstition rather than by brute force. It was the system of taboo which kept them in an organized state of society. In a masterly work, "The Origin and Development of Moral Ideas", Dr. Edward Westermarck has shown that superstitious fears have done much to restrain mankind from theft and murder, from anarchy and immorality. Keeping to our special topic, we can, in conclusion, cite only a few cases out of many given by Dr. Westermarck in his interesting book.

In Ceylon, when a person wishes to protect his fruit-trees, he hangs some grotesque figures round the orchard and dedicates it to the evil spirits. No native will then dare to touch the fruit. Even the owner himself will not venture to use it till the charm has been removed by a priest. Some Indians simply surround their plantations with a single cotton thread, and it is believed if any trespasser broke the thread he would die. The negroes of Africa are usually afraid to rob each other for fear of being killed by fetish magic.

Breton belief in the efficacy of the death-vow in avenging wrongs

In modern Brittany the present writer found that many of the peasants believe that a thief or a perjurer can be made to die of a disease lasting for several months by performing the death-vow. In order to see how this was done, we asked one of the rustic wizards to help us to avenge ourselves on an imaginary man for an imaginary wrong. We were conducted at midnight along the banks of the Jaudy, near Tréguier, to a patch of ground on which there had once stood an ancient shrine to St. Yves. The wizard made us kneel down, and then knelt down beside us, and recited some prayers in the Breton tongue. Then in bad French he made the vow, asking us to repeat it after him: "Thou art the little saint of truth, and we vow to thee so and so. If he is right, condemn us" — the plural is always used — "if we are right, condemn him, and make him die within the appointed time."

Instead of making the vow to St. Yves, the Breton peasants sometimes make it to the image of death, carved in the form of a skeleton in some of the old parish churches. It is probable that the latter figure, in the early days of Christianity, inherited the cult of the Celtic god of death worshiped throughout Gaul and Belgium and Britain and Ireland in the belief of pagan days.

In conversing with M. Anatole Le Braz, the Breton student of folklore, a few years ago, we told him of our identification of St. Yves and the figure of death and the Celtic god of death, with reference to the still living superstition of the death-vow. M. Le Braz said that the same idea had occurred to him. Space does not permit us to give all the evidence we have collected as to the identification, but we may say that we have found various indications of the connection between Celtic deities and modern practices in ancient Irish records, medieval Welsh literature and Celtic folklore.

All this goes to support the statement made by Professor J. G. Frazer some thirty years ago in an article in which he maintained that "the system of taboo played an important part in the evolution of law and morality". The system was not the creation of a legislator, but the gradual outgrowth of a mass of superstitions, to which the ambition and avarice of chiefs and witch-doctors afterwards gave an artificial extension. In serving the cause of avarice and ambition, however, superstition also served the cause of civilization. It fostered ideas of the rights of property, of the sanctity of human life, and of the marriage tie; and, in the course of time, these ideas grew strong enough to stand by themselves, and to fling away the crutch of superstition which in earlier days had been their sole support.

We shall scarcely err in believing (concludes Professor Frazer) that, even in advanced societies, the moral sentiments, in so far as they are merely sentiments and are not based on an induction from experience, derive much of their force from an original system of taboo. Thus on the taboo were grafted the golden fruits of law and morality, while the parent stem dwindled slowly into the sour crabs and empty husks of popular superstition, on which only the most foolish minds in modern societies are still content to feed. After all, the most baseless superstition of the lowest savage is no worse in character than those silly fancies of certain wealthy women and men which are exploited by fortune-tellers and clairvoyants. The savage, at least, gets out of his superstitions some useful rules of life which go to make him obedient to the best impulses of his childish nature.

The wild, strange fancies of the savage mind have sometimes done more to promote the general welfare of primitive races than any selfishly rational ideas could have done. Clear, precise reasoning power is only an instrument; it can be misused. If a man employs it entirely to selfish ends, he may be more rational in a way than a superstitious savage, but he is less social, less human. He sins against the light.

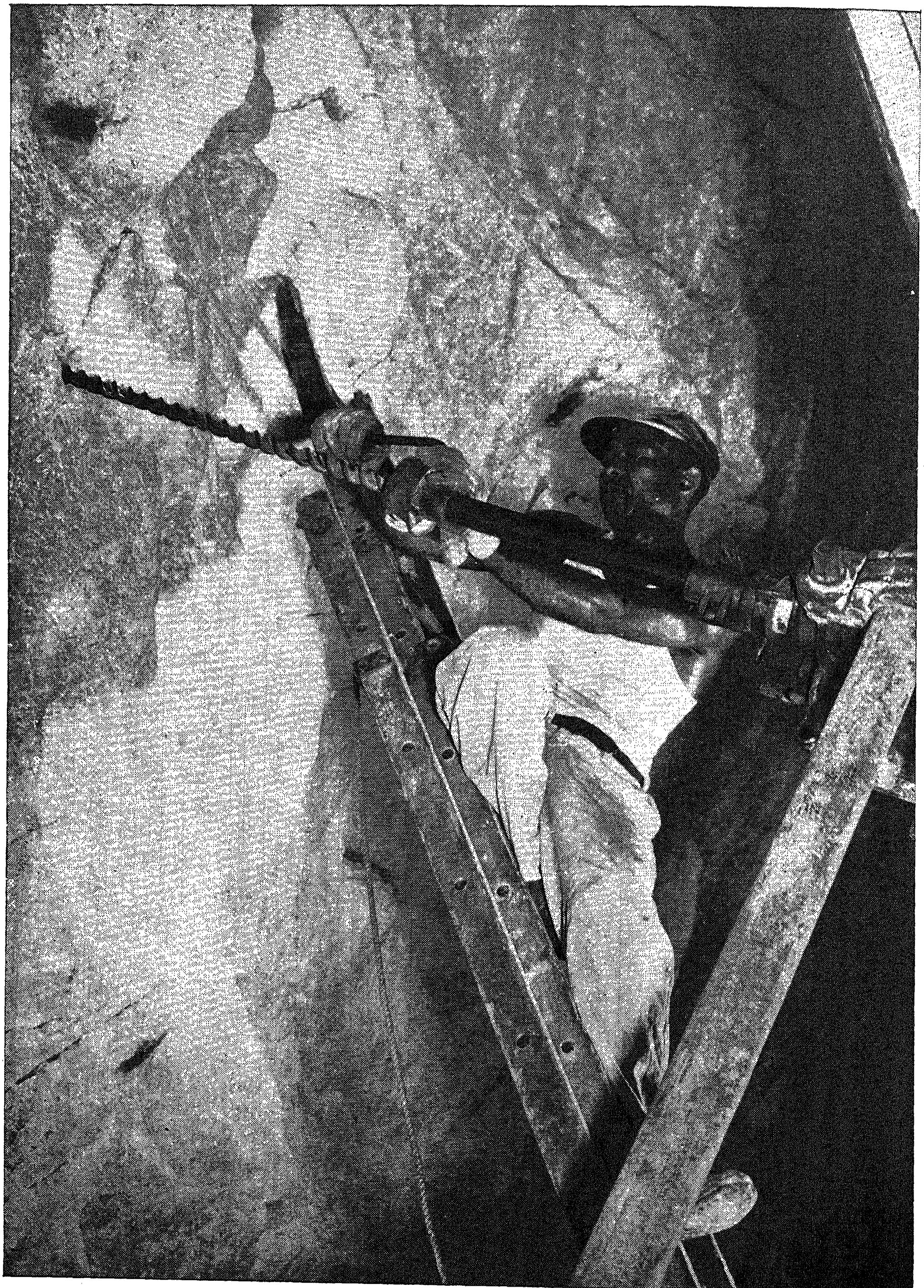
Photo E Torday

A BAPENDE MAN OF THE CONGO FREE STATE WEARING A GHOST-MASK

The savage, living in spiritual darkness, manages to obtain some good guidance in life from the most childish notions.

The system of taboo was not, of course, the only force which made for the development of the rights of private ownership. Very interesting is the later process by which land, once held in common by the tribe, came to be split up among separate owners. A great deal in the current discussion about the nationalization of the soil is based on exploded theories of the origin of the private ownership of land.

AT WORK IN A LOUISIANA SALT MINE



Louisiana Dept. of Commerce and Industry

Digging into a wall of solid rock salt in a Louisiana mine. The salt is almost 100 per cent pure.

WHERE OUR SALT COMES FROM

From the Primitive Salt-Lick to the Modern Electric Soda-Factory

THE INDUSTRY THAT LED TO COMMERCE

SINCE mankind turned from a wandering to a settled life, the obtaining of salt has been an important and vital industry. Only where savages retain the brutal habit of drinking the fresh blood of the animals they kill is it possible for them to do without common salt. There are few things more distressing than salt hunger, and one of the most dreadful forms of torture the Chinese practise is to provide a prisoner with ample nourishment but insufficient salt. Purely vegetarian peoples have from prehistoric times fought their way to the sea in order to obtain salt. This cause of migrations has recently been discerned from a study of the movements of the black races of Africa. In recent times, inland African negro tribes have been known to prize salt above gold; for a handful of it a slave girl could be bought. Mungo Park related that some negroes had a way of referring to an extremely wealthy man as one who "seasons all his food with salt" — the most extravagant form of luxury they could conceive. Apparently it is almost as bad as lighting a pipe with a ten-dollar bill. We know how highly esteemed salt was in Biblical times by the sanctity of the "covenant of salt".

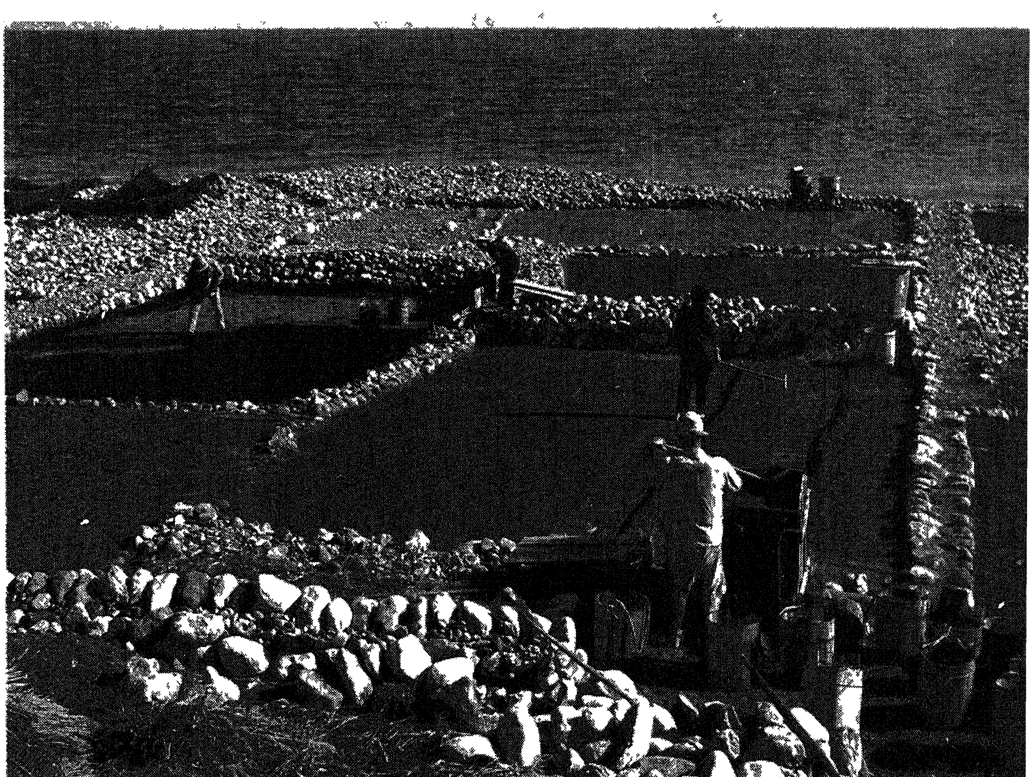
There are thus many reasons for supposing that salt was the earliest article of general barter. Food, clothing and other necessities of life the warring tribes could obtain for themselves, but inland peoples were obliged to trade for salt with seaside nations; and so commerce on an international scale originated. The rarity and dearness of salt in ancient times were, of course, due to difficulties of manufacture. It is plentiful enough in sea water. The oceans contain 4,800,000 cubic miles of salt, which would cover an area as large as the United States with salt crystals more than a mile and a half deep. There are also 325,000 cubic miles of rock-salt beds known to exist on the earth. And it is mainly from the brine pits and mines of this apparently small extent of solid beds of salt that the demands of the world are satisfied. In the United States the supply is practically inexhaustible. Not only can we take care of our own needs indefinitely but also those of the rest of the world for a long time to come.

With the progress of science and civilization, salt has grown in importance and value. For, as soon as it was known to consist of forty parts of the silvery metal sodium — which is as soft as wax, lighter than water, and caustic — and sixty parts of chlorine — a yellowish-green, heavy, irritant gas — chemists began to use it in new ways. From it they made carbonate of soda, bicarbonate of soda and caustic soda, together with hydrochloric acid and bleaching powder. Glass-makers and paper-makers, soap-makers, dyers, bleachers and wool-scourers depend now on chemicals made from common salt. From an old salt mine in Prussia there is obtained much of the potash used in various manufactures and employed as a fertilizer by the principal agricultural nations. So it will be seen that the salt industries have increased in value with the progress of civilization. Common salt is still a vital necessity for almost every race of mankind, and those that do not use it are compelled to obtain the salt they need by drinking fresh blood.

There are three principal types of salt (sodium chloride) — sea, rock and brine salt. That made from sea water is of the most ancient use. Prehistoric man constructed artificial ponds that he could flood with sea water. These ponds would evaporate in the sun leaving a deposit of white crystals useful in preserving meat and seasoning foods. From these primitive salt beds, salterns (saltworks) slowly developed. These are in use in Italy, Spain, Portugal, France and Germany; primitive types exist along all continental shores.

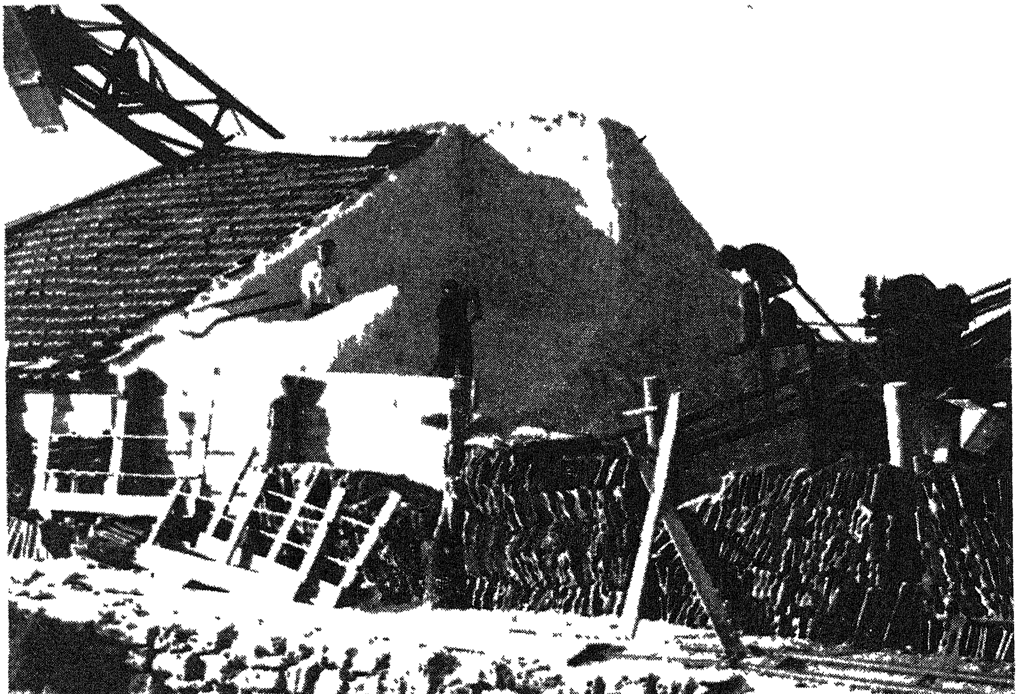
A saltern usually consists of a number of condensing beds, arranged in a slope through which brine (sea water) flows gradually, increasing in density as it approaches the last condenser. From this it gravitates or is pumped into the crystallizing beds. Often an arm of an estuary or an inlet can be banked off from the sea This forms an admirable brine reservoir, where much of the suspended matter in the water can settle, while evaporation goes on steadily. A floodgate connects the reservoir with the sea, and a pipe carries the clear water from the reservoir to a shallow pool fronting the condensing beds. Usually an open channel connects this pool with the first row of condensing beds.

Each bed has a large surface, but is only a few inches deep, so that the drying action of the air and the sun may take effect quickly. In the first beds the brine only thickens. But as it runs in gutters to the second and lower crystallizing ponds, the



Horace Bristol

Primitive saltern of Japan. Water poured over the sand evaporates, leaving salt crystals in the sand.


Screen Traveler, from Gendreau

A modern French saltern. Note the mountain of salt produced by the evaporation of sea water.

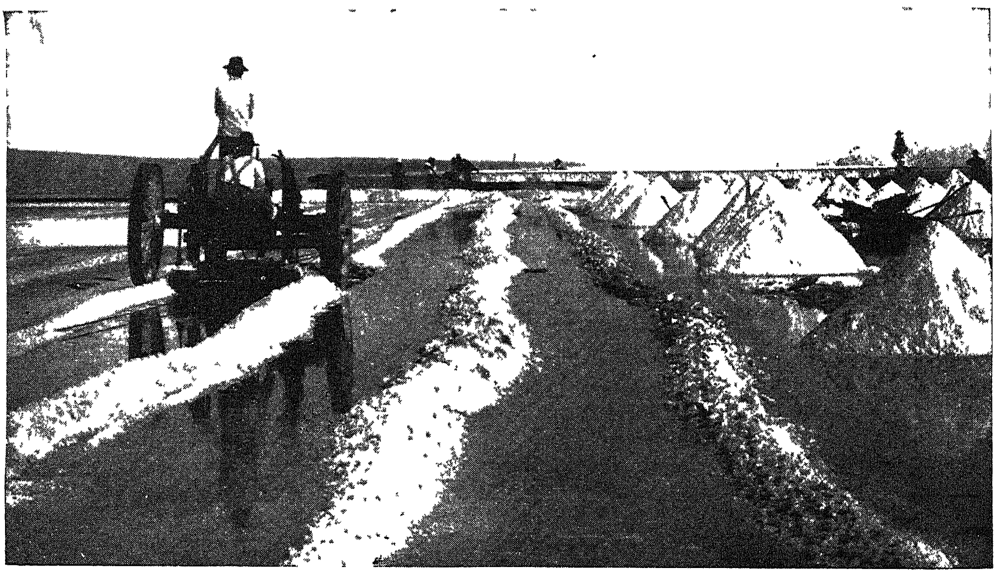
salt begins to form in a crust on the liquid, and this saline incrustation is broken up and raked into small heaps on the embankments. The sea salt, however, is at first very impure, due chiefly to the presence of magnesium chloride. This is eliminated by covering large mounds of the sea salt with straw. The straw keeps the rain off, and the moisture of the air slowly dissolves the magnesium chloride and separates it from the mass.

Formerly, the lye, or mother liquor, remaining in the last crystallizing ponds was discarded. But this thick brine is now often saved for recovering the valuable chemicals, such as magnesium sulfate and potassium chloride, contained in it. These chemicals are extracted by subjecting the waste brine to refrigeration.

Thousands of tons of sea salt can be produced annually from salterns in warm climates. But bad weather between March and September, when evaporation is being carried on, may interfere with production. For the process so entirely depends on good weather and sunlight that in wet weather scarcely any salt is formed. For this and other reasons a modern method of producing salt is by the multiple-effect vacuum evaporator. Here the brine is first treated with lime (calcium oxide) to remove impurities such as calcium and magnesium salts. Then the brine is piped into each of a series of evaporators, the first of which is heated by steam passing around it in a steam chest. Steam from the heated brine in the first evaporator passes, by way of valves, into the steam chest of the next evaporator, where it heats the brine in this second evaporator. Steam from the brine of the second evaporator passes into the steam chest of the third, and so on through the series. At the last evaporator an attached vacuum pump, complemented by a special arrangement of valves, acts on the entire system by creating a partial vacuum above the brine in each evaporator. The existence of this vacuum reduces the boiling point of the brine causing it to vaporize at lower temperatures. Each evaporator has a conical bottom, which collects the salt as it crystallizes out of the brine.

At Hayling Island, near Portsmouth, England, the manufacture of salt from sea water was carried on long before the Norman Conquest. St. Augustine praised this salt for its excellence Until a few years ago it was still made during the four summer months. The beds varied in size up to a quarter of an acre, and in favorable weather the sea water in them became brine in seven days. It was then pumped by windmills into pits, from which it ran into iron pans. It was boiled for twelve hours, and skimmed to remove impurities. The crystals were shoveled out, hot and wet, into wooden trucks, from which the mother-liquor ran off through holes in the bottom.

places it is a mining operation, and it is carried on by means of shafts and horizontal galleries. The most famous of salt-mines is that of Wieliczka, in Poland, which probably contains the largest and the purest deposit in the world. The bed is said to extend for five hundred miles, with a breadth of twenty and more miles, and a depth of 1200 feet. Being an underground city, hewn in the course of ages in glistening rock salt in the heart of the earth, the Wieliczka mine is a most surprising monument of human labor. It lies below the quiet Carpathian valley of the Vistula. The Cracow railway runs some miles away, in order to prevent the dangers of vibration.



HARVESTING SALT WITH A PLOW FROM DEPOSITS IN THE CALIFORNIAN DESERT

It is thus seen that the concentration of sea water for salt by solar evaporation is a rather uncertain industry except in the warm dry climates. The cost of fuel and labor, together with the fact that sea salt, is apt to be of inferior quality as well as coarse, prohibits evaporation over a fire. Our country, rich in rock and brine salt, has made comparatively little use of the salt found in the sea itself, although the sea salt plants of California are still of interest to the tourist of the Pacific Coast.

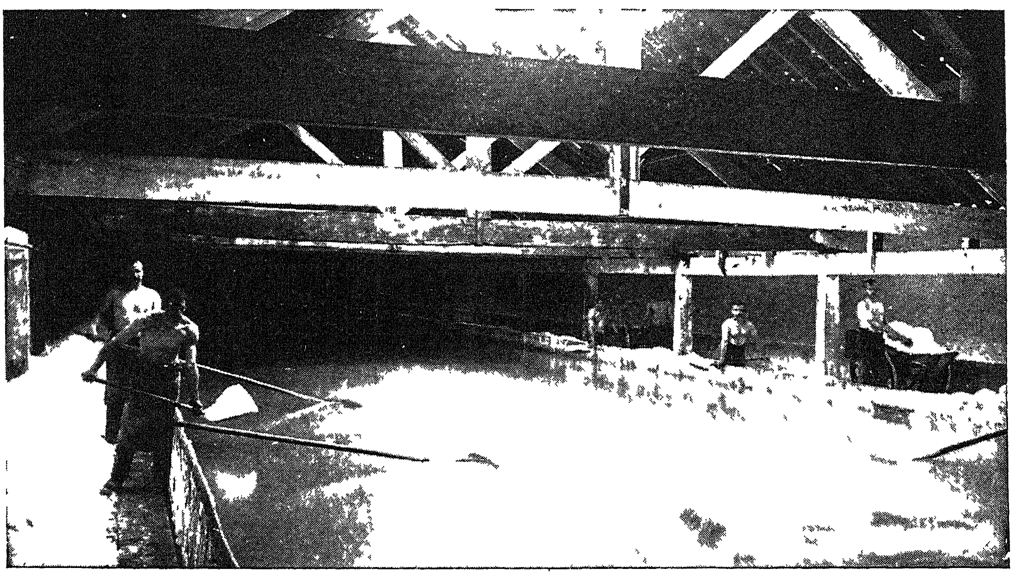
The way in which deposits of rock salt are worked depends very much upon the locality, the depth of the bed, the price of fuel, the rate of wages and so on. In some

Hundreds of years of patient human toil have honeycombed out of the solid rock salt an entire city at various levels. It consists of an intricate maze of winding streets and dim, scintillating alleys, of pillared churches, diamond and ruby staircases, restaurants, railroad stations, shrines, statues, monuments and a thousand other wonders — all rough-hewn in the sparkling rock salt crystals which, when lighted by electricity, pine torches, magnesium flashes or thousands of candles, blaze like a world of precious stones. Elevators descend to this fairy city, but there is also a long staircase cut from the solid rock, which flashes ruby and emerald at every step.

About two thousand men work night and day in the underground city in eight-hour shifts. The mine has been worked since 1251, yet its resources have scarcely been touched, so immense are they. What distinguishes the Polish miners from all others is their love of art. Far from being depressed in their strange underground city, they have, for some hundreds of years, given a great deal of their spare time to carving huge monuments and innumerable statues out of the glittering rock. Emulation must have been the secret of all their gigantic art work. It seems that no sooner was the first shrine chiseled from the salt, the first statue carved, than succeeding generations of miners were fired with zeal and determined to exercise their genius for sculpture. The salt-hewn cathedral of St. Anthony dates from the seventeenth century, and was planned by a pious foreman. The miners carry their religion with them to the depths of the earth, and strange and touching services are held in the rock salt churches. Many of the men are musicians, and they have their own orchestra for festive occasions.

Some 300 feet away from the cathedral is a magnificent cavern cut from the rock. It is over 300 feet long, and towers to a height of 190 feet. Along its flashing walls are great statues of Knowledge, Labor and other symbolical figures At one end is a rock salt throne of state, formerly kept for the use of the emperor of Austria-Hungary and the imperial archdukes. Whenever an old working is exhausted and closed, or a new street opened in the subterranean city, the event is celebrated by a dance in the great hall. Hundreds of picturesquely clad peasant women — wives, sisters and sweethearts of the underground workers — take their partners into the cavern, where shrill pipes and soft flutes and violins make merry music as the couples whirl in wild Slavonic dances.

What adds to the strange beauty of this subterranean city is the illumination. The immense halls, restaurants, churches and other public buildings are lighted by great chandeliers of salt crystals. One of them is 10 feet in diameter and 20 feet high, containing about two hundred and forty candles. There is a central railroad station, where all the little traffic lines of the city of salt meet. It is three centuries since it was made the center of the town. Many of the principal streets converge upon it. The lines are narrow gauge, the little cars being drawn by Polish ponies, most of which have never been on the surface, and are born blind. The platform of this great central station has seating-room for four hundred persons.



DRAWING THE SALT USED IN CURING FISH, ETC., WHICH HAS SETTLED IN THE BRINE-PAN

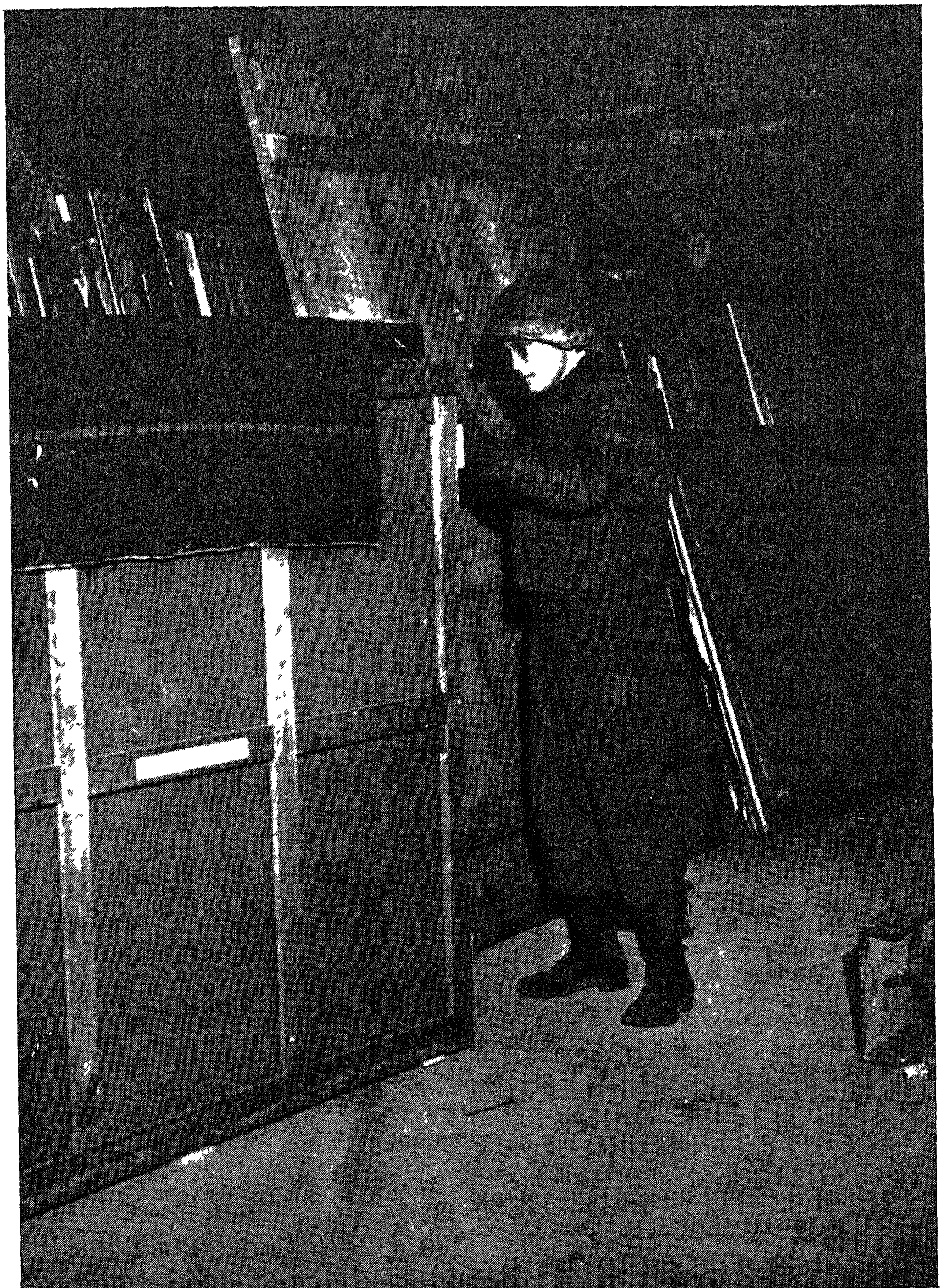
On holidays its cafés are crowded with visitors from the upper world, who take their meals to the wild music of the miners' orchestra that echoes and reverberates strangely through the dim and yet sparkling streets.

There are also waterways in this weird city. In many places the saline lakes are from 20 to 30 feet deep, and over them ply ferry boats, holding a couple of dozen passengers. The boats give access to the remote and very ancient parts of the mine, such as the Stephanie Grotto, where rock-hewn statues of medieval saints arise out of the dense salt water, girt and enshrined, as it were, by curiously beautiful salt stalactites and stalagmites. The lakes are fed by subterranean springs, and they are a source of peril to the miners, for they sometimes rise suddenly and drown the workers in the lowest galleries. The inhabitants lead, indeed, a hazardous as well as a hard life. Great masses of rock salt, often weighing hundreds of tons, fall now and then in avalanches from the domed roofs of the streets or the ceilings of new chambers.

Besides floods, fires and falls of rock — all of which catastrophes put on a ghastlier horror in the depths at which they occur — there is another serious danger of violent explosions from the gas that accumulates in newly excavated galleries. Yet for centuries these disasters have not daunted the thousands of inhabitants of the strange city of salt. Children are born and christened in the underground caverns, and, growing up, they continue the work of their fathers. Extending along the Carpathian Mountains for five hundred miles, the rock salt out of which the churches and halls of Wieliczka are built is mined at many other places — in upper Austria and Hungary, in Tyrol and Styria, in Transylvania and Wallachia. While this great bed of salt in Poland is the largest known, there are many similar smaller ones in other lands. Many of them made their presence known to man centuries ago through salt springs that rose from them.

Geologists are not agreed as to the exact manner in which these great beds of salt were formed and buried deep in the earth. Perhaps the most commonly accepted theory is that the areas on which they rest formed at one time the bed of large, shallow ponds near the ocean and so situated that the salt water could flow into them but to no great depth. Constant evaporation by the sun left these great deposits of salt, and subsequent geologic changes buried them under many feet of stone and earth. Quite recently another explanation of the formation of salt-beds has been advanced in connection with the mines of Louisiana, which differ from the others in being close to the surface and which are famous for their remarkable purity, their product containing 99½ per cent of sodium chloride. The theory advanced is as follows. It seems that the older rocks in the Mississippi region all slope toward the south at a much greater angle than does the surface of the ground. Water entering fissures of these rocks in Arkansas, for example, would flow south and find itself thousands of feet below the surface when it reached the Gulf of Mexico It would naturally become very warm as compared with surface water and would easily dissolve soluble substances like salt. If, now, a break or point of weakness occurred in the upper beds of rock, the water would work its way to the surface after the manner of water in an artesian well. But as it rose it would cool and some of the salt held in solution would crystallize and gradually a mass of solid salt would be formed. The strength of a growing crystal is known to be sufficient to overcome almost any resistance, and it has been claimed that such growing crystals of salt have lifted part of the Gulf Coast at least 3500 feet thick. With brine supplied to the salt mass from below, crystallization naturally takes place mainly on the bottom, especially after the column has attained considerable dimensions. The resultant movement upward of these great salt masses accounts for the proximity to the surface of the Louisiana mines. This theory, while plausible, has not been accepted by all geologists, and we shall probably have to wait some time before we know with certainty how these valuable deposits were formed, possibly differently in different cases.

A SALT MINE THAT GUARDED ART AND GOLD



Acme Photo

A scene in the salt mine at Moeckers, Germany, toward the end of World War II, after American troops had overrun the area. An American art expert is inspecting crates containing paintings; the German authorities had stored these art treasures in the corridors of the mine in order to preserve them from the aerial bombs of the Allies. The Americans also found German gold reserves.

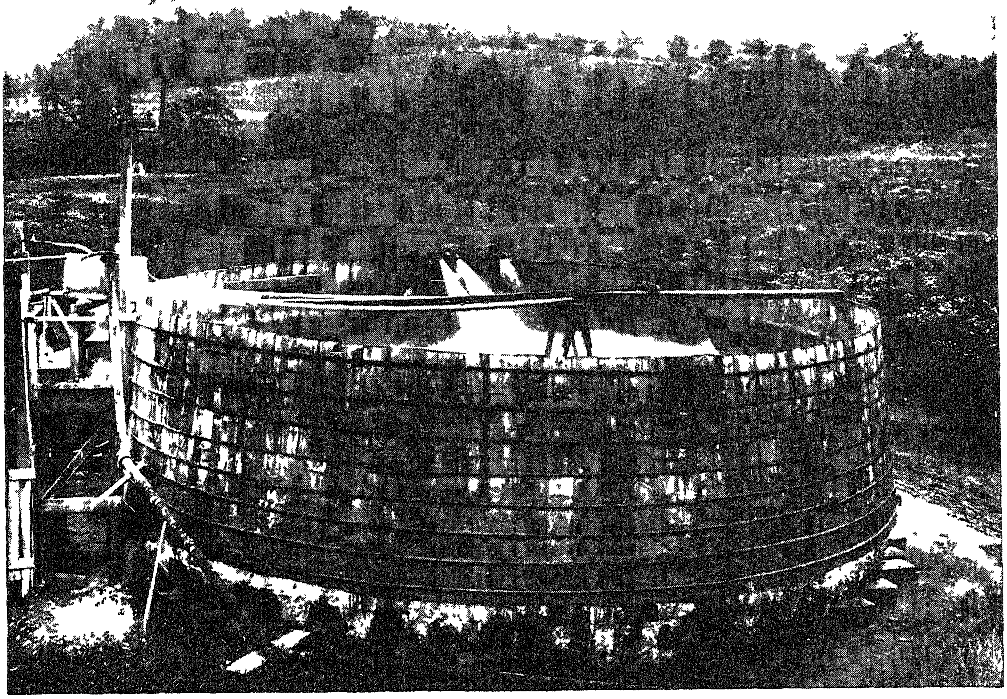
In America rock salt is produced by deep shaft mining in the eastern, central and southern sections of the United States There are salt mines in Michigan, New York, Kansas and Louisiana Salt is also made, still, from springs and salt lakes by solar evaporation but the greater part of the industry is based on buried deposits In Kansas four rock salt mines are found near the central part of the state The earliest work in this district was done about 1890, while the Louisiana mines date back to 1862. The Michigan field, near Detroit, produces a very good grade of salt, which only needs grinding to prepare it for table use. The vein lies about 1150 feet below the surface, and until very recently this was the deepest salt mine in the world. Central New York, now boasts the deepest shaft ever sunk for salt mining and, incidentally, the most up-to-date mine equipment yet installed. This shaft, which is on the shore of Cayuga Lake, one of the "finger lakes" left by the receding glacial cap, is 23 by 11½ feet and 1500 feet deep The vein is 60 feet thick and of excellent quality Over one million feet of hickory and white oak have been used in the underground construction, besides vast amounts of concrete.

Many difficult problems arise in connection with salt mining. In Michigan, for example, underground water and quicksand were encountered, making it necessary to resort to the clever scheme of running refrigeration pipes through the troublesome section, thus keeping the sand and water frozen solid until the shaft was concreted.

Salt "licks" and springs are found in nearly all the states of our country. Those of southern Illinois were worked by the French and Indians in 1720, and it is recorded that the famous Kentucky salt springs were known and used before 1790. One of our most remarkable salt works is at Salton, California. A marshy lake, 28 feet below the level of the sea is continually fed by numerous springs in the surrounding foothills. This lake is rich in brine and its waters, evaporating quickly under the warm sun, leave deposits of almost pure salt varying from 10 to 20 inches in thickness. On account of the extremely high temperature in this dry climate, only Mexicans have been able to do the work of collecting and shipping the hundreds of tons of salt which have been daily taken from the lake.

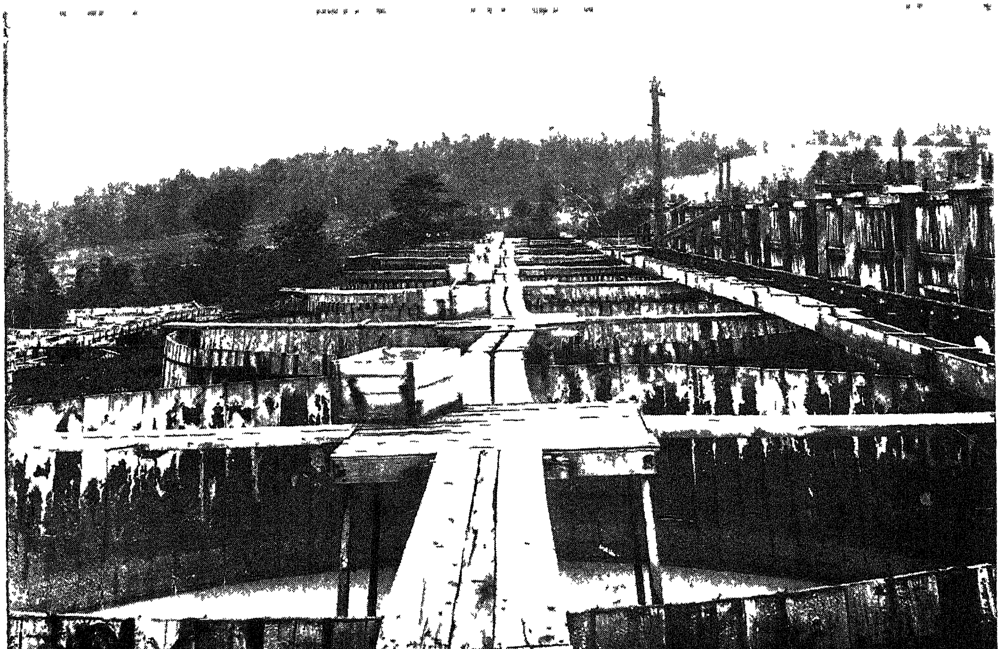
In the United States most of the salt is obtained from the brines by some sort of artificial evaporation. With the exception of a few subterranean lakes, or pockets of brine, the deposits are in the form of rock salt and must be dissolved by water led down through long pipes. A well similar to that used for crude oil is first drilled and a heavy steel casing of about 10 inches in diameter inserted simultaneously with the drill. This casing serves to keep out water and materials which would impede the progress of the drill. When the drill has reached bed-rock and the casing has been driven home, the lower part of the well may be finished with a smaller drill which descends to the bottom of the salt vein. Then a smaller 6-inch casing is lowered to the bottom of the well and an effective joint made between the two pipes. Thus the finished well consists of a line of tubing 10 inches in diameter down to the solid rock and 6 inches in diameter below the rock level. Two pipes of smaller diameter and arranged concentrically are now inserted to carry water and compressed air. Fresh water is forced down to the bottom and gradually the dissolving process on the salt-bed begins. It should be noted in this connection that large quantities of pure water are demanded in the salt-making business, as well as in many other industries. This accounts for the presence of many of our salt plants on the inland lakes and rivers.

In some countries the use of the brine process has caused much trouble because of the dissolving of the salt-beds which were fairly close to the surface. There is no chance to support the undermined ground as in the case of salt mining, and, as a result, a gradual, sometimes a sudden, settling of the surface has occurred not unlike that caused by an earthquake. In our own country the salt vein is usually found at some depth and covered with great thicknesses of rock, which form a very sure support for the surface material.



PUMPING UP A SALT BED

Water is forced down to the buried layer of salt through one pipe and the brine so formed is forced up another or uptake pipe The brine is here seen flowing from an uptake pipe into the settling tank



Courtesy International Salt Co

LOOKING DOWN ON EIGHT OF THE SETTLING TANKS

Many of the impurities separate out before evaporation.

The pressure in the down-flow pipe causes the brine to ascend the uptake pipe. The brine which ascends is a rather heavy liquid and must be relieved, not only of the water which has been added to allow it to pass through the pipes, but of several undesirable chemicals as well as sand and dirt. For this reason it is allowed to remain for about 24 hours in settling tanks and where chemicals may be added if necessary to hasten the separating action. The next step in the refining process is one of artificial evaporation This is generally accomplished in one of three ways, although no two plants agree in all the details of the process. The first is the old "kettle" method in which the evaporation is carried on in iron kettles of about 4 feet diameter, set in rows of 16 to 25 over a flue leading from the furnace to the chimney. The brine is delivered to the kettles through a pipe which runs the length of the rows. After a time it begins to crystallize on the sides of the kettle. It is then raked out, placed in a perforated basket and set over the kettle where it continues to crystallize and drain back its moisture into the kettle. This method has been generally abandoned in this country because of lack of economy in fuel consumption and because only one grade of salt can be produced, and that rather poor.

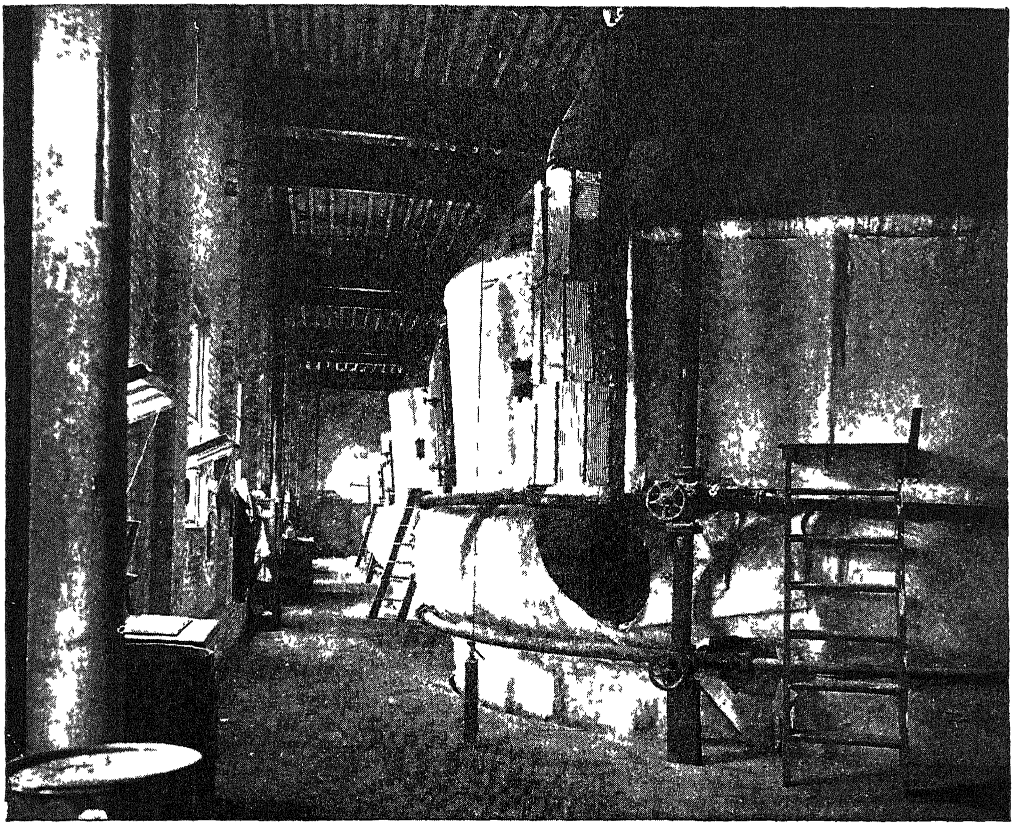
In Michigan and New York, the two states that produce three-quarters of the country's salt, two other methods are usually found working in combination. This is done because there is a desire for more than one quality of salt and neither method alone affords much variation. From the settling tanks the brine is led either to "grainers" or to "vacuum-pans." The "grainer" is simply a development of the "kettle" method, while the idea of using vacuum-pan evaporation was borrowed from the sugar refining industry. All of these processes are based upon the fundamental idea that substances which crystallize can be obtained in a state of comparative purity by allowing the crystals to form in the mother liquid. They also make use of the fact that the higher the temperature of crystallization, the finer the crystal formed.

The grainer is simply a wooden or steel trough, 12 to 18 feet wide and 90 to 150 feet long, in which steam pipes are suspended a few inches from the bottom. The brine flows in to a depth of about 14 inches, a level automatically maintained by a float valve. The foaming crystals sink to the bottom of the trough, whence they are slowly pushed to a sloping drain, and shortly after on to a conveying belt by means of an automatic feathering rake. The grainer salt is of the variety used for pretzels or in certain packing processes where the finest grade of salt is not needed.

The "vacuum-pan" process is extensively used because of the excellence of the product and because it is very economical. The name is really a misnomer, as the illustrations show. The "pan" is not a pan at all but, in the form most generally found, consists of two cones set base to base on a short cylindrical section, in which are many hundreds of copper flues, open at both ends. The brine is run into the pan till it fills the lower cone and that part of the cylindrical section that carries the tubes. Steam is then allowed to enter through various openings into the middle section, and at the same time the air is pumped from the brine. This, of course, lowers the boiling point of the latter so that it is unnecessary to supply as much heat through the steam as is required in a system which evaporates at atmospheric pressure. The cost of fuel, of pumping the air, of upkeep on the various members of the system will determine the most economical pressures and temperatures at which to operate.

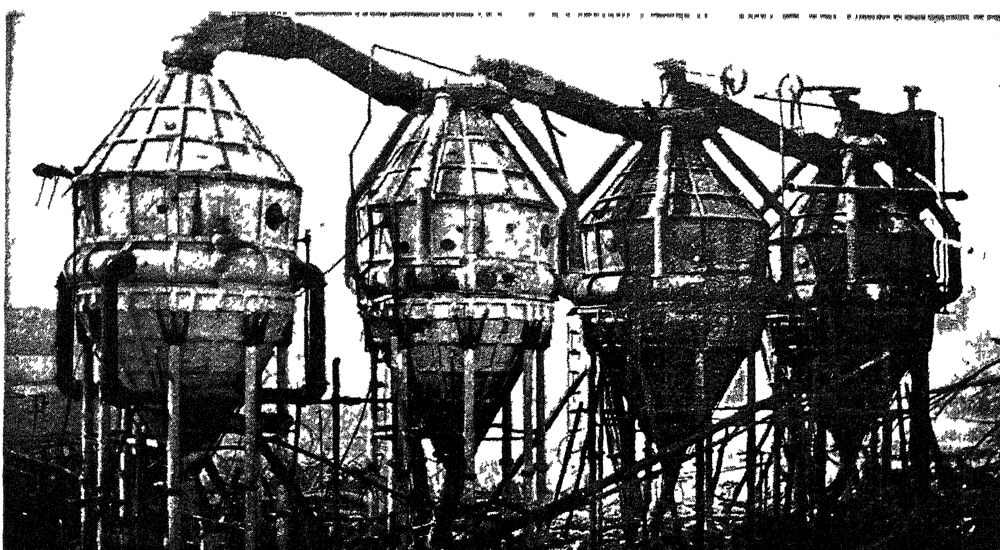
As the brine boils in this pan it will give off vapors which must be withdrawn to some sort of a condensing chamber, otherwise the influence of the air pump would soon be counteracted. In a multiple effect pan such as shown in the illustration the pans are connected in series so that the vapors from one pan are used to heat the adjacent one, the air pressure gradually dropping through the series. In this particular installation the pressure on the brine varies from 14 to 28½ inches of mercury on a certain day in February when the condensing water was very cold.

A VACUUM-PAN PLANT



INTERIOR OF A VACUUM-PAN PLANT

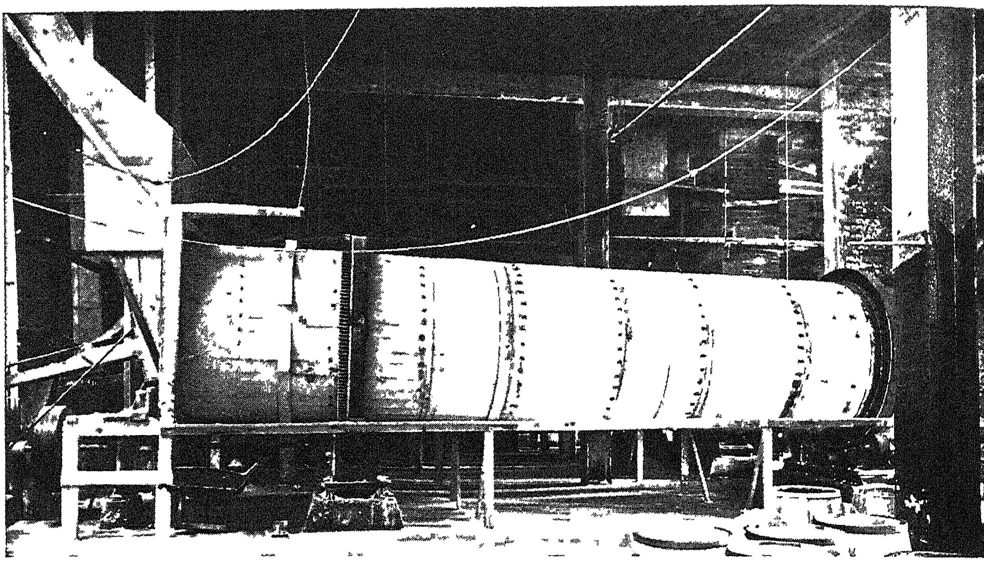
The floor is rather less than halfway up the pan. The steam belt surrounds the pan just above it.



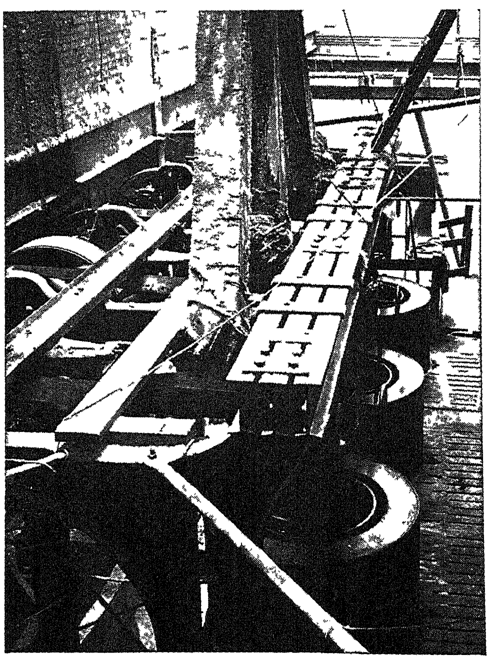
Courtesy International Salt Co

WHAT THE PANS REALLY LOOK LIKE

It is difficult to obtain a good view of a vacuum-pan installation when in operation. This illustration shows a "quadruple effect" plant taken after a fire had burned away the surrounding building.



The long cylindrical drier which slowly rotating throws the salt against a heated pipe in the center of the shell



DRYING THE SALT

Looking down on a battery of centrifugal driers In these the salt is rotated at a very high speed and centrifugal action drives the water out of the salt, the latter being restrained from flying outward by strong screening

In this way the steam is made to pass successively through all the pans, and if all works well in a four-pan outfit, one pound of steam may be made to evaporate $3\frac{3}{4}$ pounds of salt water. The scheme may be roughly compared to the use of steam in a quadruple expansion steam engine.

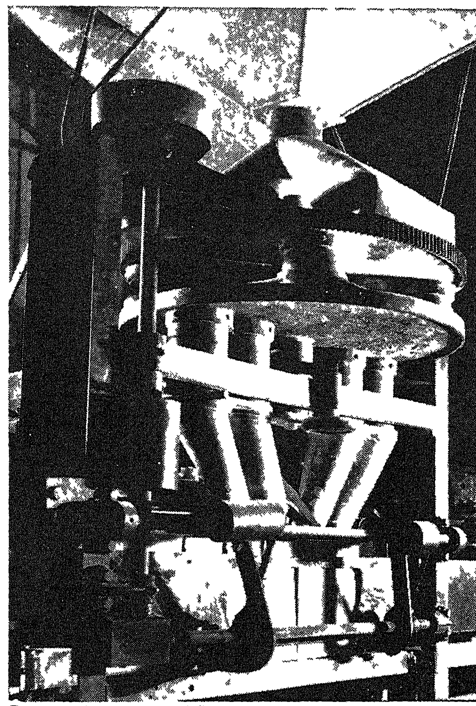
It should be added that this method of refinement is not without its difficulties. Experts must watch each change in pressure and temperature and regulate the system with judgment. A few minutes of inattention may cause hours of shut-down.

The salt as it comes from the grainer or vacuum-pan still contains some moisture which must be removed before it can be stored or packed for shipment. The endless belt in the case of the grainer, and the endless chain elevator in the case of the vacuum-pan, deliver the salt to centrifugal driers where most of the remaining moisture is removed. The salt may be now stored in heaps on the floor of the curing room, or it may pass at once through a long cylindrical drier filled with baffle plates which force the salt to drop on a central heated pipe which takes away what little moisture still remains. Much of the finest salt undergoes a month's curing process as it lies stacked in the curing room. These mountainous heaps of salt are often a source of danger to the workmen as they shovel it into the barrels or bags. On many occasions the undermined, overhanging cliff suddenly collapsed, bringing death to the buried workmen. To obviate this danger the holes are drilled with an electrically driven auger near the base of the cliff, thus bringing about a gentle collapse which could be guarded against.

The packing of salt into barrels or large sacks is still largely done by hand. In the case of smaller sacks and cartons, automatic machinery is employed which weighs the desired amount of the finished product for each container.

In considering the uses of salt one naturally thinks of it first as a food. The finest table salts, made in the latest type of vacuum-pan, are not only sifted to a flour-like fineness, but are treated in such a way as to prevent caking in the shaker. All of the commercial salts carry with them certain deliquescent salts which will draw an amount of moisture from the air. To overcome this tendency various moisture absorbers are used, principally very small amounts of cornstarch or calcium phosphate. It is possible by the use of steel-jacketed mixers to so combine these materials with the salt that there is no appearance of dustiness in the finished product. Large quantities of salt are now in use in refrigeration plants where salt brine is used as a cooling medium. Hides, meat, fish, butter and many other products use their share of the 7,000,000 tons of salt our country produces annually.

Perhaps the real cause of the increased output during recent years has been the tremendous growth of many of our chemical industries which require salt as a raw material. A shortage of materials usually imported as well as a greater demand for the exportation of certain chemicals, the great development of the hydro-electric power plant enabling more efficient use to be made of the electric furnace, and the general expansion in all our industries help to explain it. As has been mentioned, salt consists of the two chemicals, sodium and chlorine. It is possible to separate these and, by another combination, produce the household necessity — soda. A Frenchman, Leblanc, invented a method of accomplishing this result many years ago. His scheme required the use of oil of vitriol for treating the salt. It was not long before a Belgian, Solvay, invented a similar process, using ammonia instead. The later developments improved the Solvay process to such an extent that the Leblanc method would have been discontinued had it not been for the fact that two other very valuable products, hydrochloric acid and chlorine, were also produced by it. In this way the materials that were at first by-products became the leading products. Bleaching powders all depend for their action on chlorine, so a new industry was established. On the other hand no successful means has yet been discovered for obtaining bleaching powder from an ammonia soda plant. At Syracuse the Solvay process is in use and many sodium compounds are produced in great quantities.



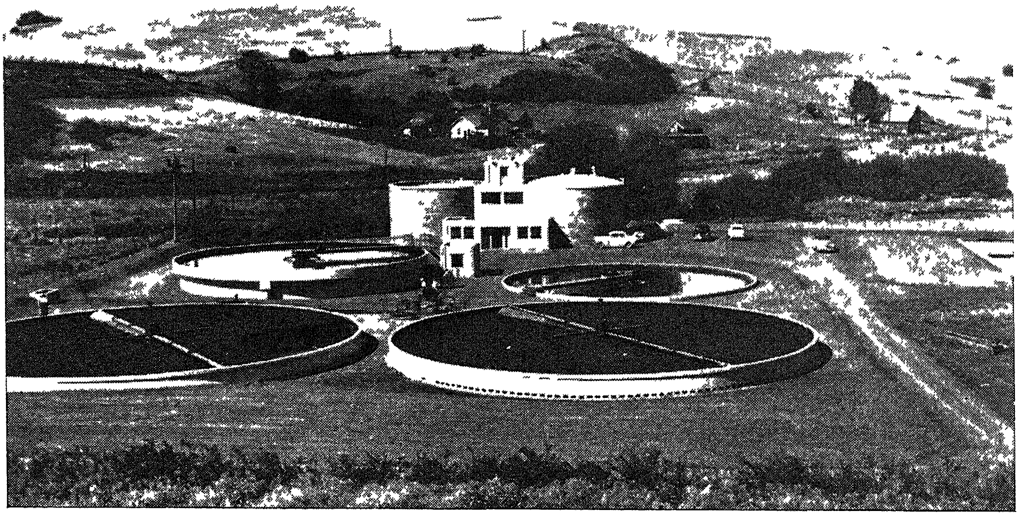
Courtesy International Salt Co

PACKING SALT BY MACHINERY

Such weighing machines insure uniform contents in all packages with mechanical accuracy

At Niagara Falls, very important in the chemical industry of the world, an electric system of dissolution has been used for several years. When a strong current of electricity is passed through a brine solution, the chlorine escapes as a gas, and being led through lime chambers forms the chloride of lime or bleaching powder. The sodium by another chemical reaction may be converted into "caustic" soda or sodium bicarbonate, sodium nitrate or other valuable chemicals.

GOOD AND BAD WASTE-DISPOSAL SYSTEMS



This modern sewage-disposal plant is located at Pullman, Washington. Foreground: trickling filters; left center, primary settling tank; right center, final settling tank; background: digesters.

The open-dump method of refuse disposal, illustrated above, is unsightly and unsanitary. Open dumps offer a haven for flies, rats, lice and other vermin; dumps also constitute a serious fire hazard.

THE DISPOSAL OF WASTES

How Modern Communities Deal with an Age-Old Problem

by

W. S. FOSTER

IN any community, large or small, an astonishing amount of waste materials accumulates in the course of a single day. There are human wastes resulting from the chemical changes that food and drink undergo in the body. There are large quantities of household wastes. The housewife cuts away certain portions of vegetables and other foods in preparing a meal; after the meal, meat bones, fruit rinds and uneaten food must be disposed of. Old shoes, boxes, crates, cartons, useless articles of metal and rubber, discarded toys and what not add to the pile of refuse. There are industrial wastes, too, resulting from a vast variety of manufacturing operations. All of these waste materials must be disposed of in some way or other; the health of the community will depend upon the promptness and the effectiveness with which this particular task is accomplished.

In the average fair-sized community certain wastes are carried away by water through a sewage system. Others, such as garbage, trash, ashes and brush, are collected periodically and carried to a central disposal plant.

SEWAGE DISPOSAL

Sewage disposal as we know it today is a recent engineering practice. There were sewers in antiquity in India, Rome and a few other places; but they served mainly to collect storm water or, like Rome's famous Cloaca Maxima, to drain marshy areas. In the Middle Ages sewage flowed along open drains that ran through the streets. Later it was carried in conduits to open cesspools located in the outskirts of cities. It was not until the nineteenth century that modern practices of sewage disposal were widely adopted. Even today, in many communities, particularly in the Far East, men come to homes at night, collect night soil (human wastes) and carry it away in carts.

In certain places, particularly China and Japan, night soil is used extensively as fertilizer; that which is collected from the wealthier sections of the community commands the highest prices. This practice has its good points, since it returns to the soil certain valuable organic materials that were taken from it when the crops were harvested. However, most of us dislike the idea of having human excretion hauled through the streets; and health authorities do not like to have us eat raw foods grown in excretion-fertilized soil.

Our sanitary engineers use an entirely different method of disposing of human wastes and certain other types of refuse. They collect them in a system of sewers, bring them to a sewage-disposal plant, treat them so as to render them harmless and then empty the purified sewage into seas, lakes or rivers.

In the best system the sanitary sewers servicing our homes are separate from the storm sewers that take the storm waters from our streets. In the older systems, however, sanitary and storm sewage are carried in the same pipes. It is easy to understand why sanitary engineers are opposed to such combined sewers, as they are called. After all, storm water is rain water; except for a little debris that is washed off the streets, it is unpolluted and it is not necessary to treat it before it is emptied into a receiving stream. It is sheer waste to build sewage-treatment plants that will have to be big enough to treat not only sewage but also comparatively pure rain

water that requires no particular treatment.

Sewer pipes and conduits are generally made of vitrified clay or concrete. Occasionally pipe made of iron, of steel or of asbestos and cement is employed, but only for special purposes. When clay pipe is laid carefully, it makes an excellent sewer; it will last almost indefinitely. Concrete is also a good material for this purpose. Since it may be affected by the acids or corrosive gases in the sewage, the concrete is sometimes lined with clay blocks, or else it is painted with an acid-resistant coating.

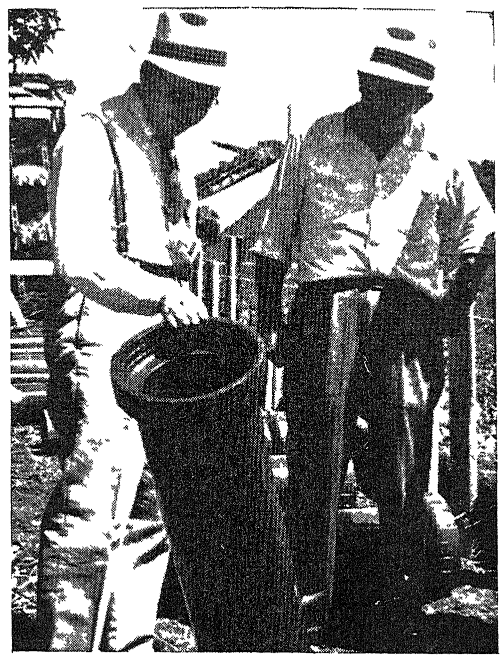
Sewage is made to flow to the treatment plant by means of gravity if that is feasible. If the ground is too flat, or if hills intervene along the course of the sewer, engineers install pumping systems. These raise the sewage high enough so that gravity will cause it to flow steadily to the treatment plant.

Sewage is made up chiefly of water; there is only about one pound of solid matter in a ton of typical sewage. This solid matter represents a constant menace, for it is an ideal breeding place for disease germs of many different kinds.

Suppose that we simply emptied the sewage into the nearest stream; is it not true that, as the popular notion has it, the stream will purify itself? This question cannot be answered with a simple "Yes" or "No."

Unpolluted streams carry a certain amount of dissolved oxygen. Suppose we empty a quantity of sewage into a stream like this. The waste matter will use up oxygen as it decomposes; if there is enough oxygen in the stream to meet this demand, the stream will indeed have purified itself by the time the wastes are entirely decomposed. This is likely to happen if the stream in question is large, if it is turbulent so that the air comes into frequent contact with the water and if the stream has to receive only a small amount of sewage.

However, if the sewage is very strong or if too much of it is emptied into the stream, the reserves of dissolved oxygen in the water will be used up and the stream will become polluted. The effects will be very serious. Not only will the stream be terribly odorous, but it may be ruined as a



Examining a length of vitrified-clay sewer pipe, which is to be used in a sewer in Wichita, Kansas Vitrified clay is a fine material for this purpose.

source of water for drinking and industrial purposes, and fish and other animal life within it will be menaced.

Stream pollution represents a serious economic loss. For example, the salmon catch in streams along the eastern coast of the United States once amounted to millions of pounds a year; today, because of water pollution, salmon has almost completely disappeared from these areas. Thousands of acres of oyster and other shellfish beds along the eastern coast have been ruined by water pollution. It has also greatly reduced the number of areas that can be used safely for bathing purposes; beaches that once offered recreation to many thousands have become menaces to health, with dangerously high concentrations of harmful bacteria.

That is why the modern sanitary engineer goes to such elaborate pains to treat sewage so as to render it harmless before it empties into the receiving stream. The method of treatment will depend upon the quantity and the nature of the solid wastes within the sewage. To measure these all-

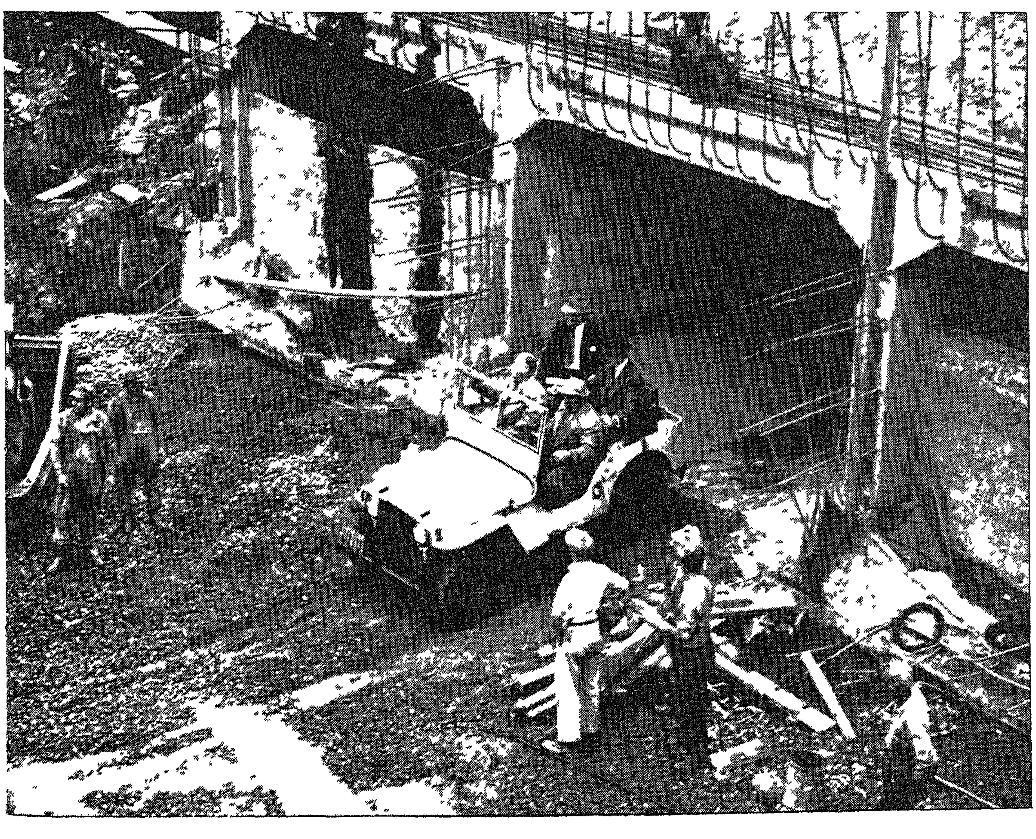
important factors, the engineer uses several yardsticks. Two of the more common he calls "suspended solids" and "biochemical-oxygen demand." Another that is useful in measuring industrial wastes is called "equivalent population."

He calculates the amount of suspended solids in a given quantity of sewage in order to find out how much bulk he will have to treat. The solids in sewage may be divided into fixed and volatile materials. The fixed solids are the inorganic matter, such as sand, that will not decompose further and that will not cause any particular damage to the receiving stream. The volatile solids consist of organic matter that is in the process of decomposition. This is the type of matter that is particularly dangerous and that the sanitary engineer must attack with all the weapons at his command.

When we speak of biochemical-oxygen demand (or BOD), we have in mind the amount of oxygen used up in the process of decomposition under natural conditions. Biochemical-oxygen demand is determined by special tests; it is a measure of the harmful potentialities of the solid wastes.

In order to have a clearer idea of how strong certain industrial sewages are, sanitary engineers often use the term "equivalent population" in describing them. This means that the amount of suspended solids that a given industrial waste contributes to the sewage is measured in terms of the wastes contributed by the population at large. For example, each person adds between 0.15 and 0.18 pounds of suspended solids per day to the sewage. Thus, if an industrial waste contributed 170 pounds of solids a day, it would add as much to the sewage as approximately 1,000 people.

The United States Public Health Service



Scene at a sewer-construction project in the borough of Queens, New York City. The sewer is so large that the inspection party shown in the center has had no difficulty in driving through it in a jeep.

has analyzed certain representative industrial wastes and has given us these figures:

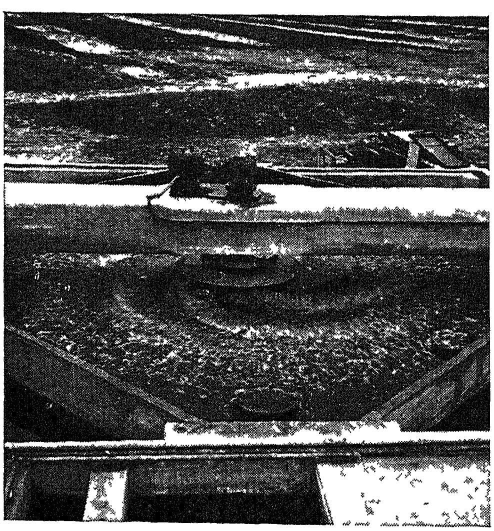
Meat packing: Processing a hog produces waste equal to that contributed by 24 people.

Laundry: Processing 100 pounds of clothes produces waste equal to that contributed by 24 people.

Creamery: Processing 100 pounds of butter produces waste equal to that contributed by 34 people.

After the sewage has been directed to a sewage-disposal plant and its contents have been analyzed, the sanitary engineer is ready for the challenging task of rendering it harmless and, in certain cases, even useful.

One of the first measures he adopts is that of screening. As the sewage enters the treatment plant, it passes through a set of screens that remove coarse suspended matter such as rags, sticks and floating orange peels. In the smaller plants, the operator rakes this material off the screen and hauls it away to be buried. Larger plants often use grinding machines that automatically rake the material off the screen, grind it and then return it to the sewage flow. Some plants dispense with screens entirely; the sewage passes through a grinding machine, called a comminutor, which shreds the coarse material as it flows by.



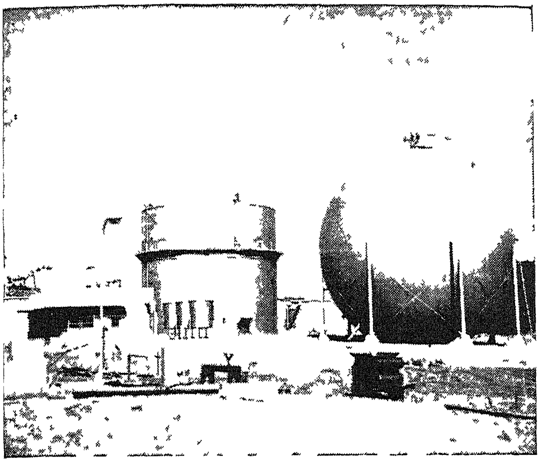
Aeration tank in an activated-sludge plant. Aeration is provided by the paddles spinning on top.

The next step is to remove heavy inorganic matter, such as sand. The sewage is directed through a compartment known as a grit chamber. This is so designed as to allow the sewage to flow through it at some established rate, such as one foot per second, regardless of the amount of sewage entering the chamber. If this rate of flow is constantly maintained, the sand will drop to the bottom of the chamber. Here it is cleaned out by mechanical scrapers or hand scrapers

Next, some of the finer material in the sewage is removed by settling. The settling tanks in a sewage-treatment plant are very much like those used in a water-supply system. They hold the sewage for some specified length of time, say two or three hours; in the course of this time a substantial portion of the sewage material settles to the bottom of the tanks as sludge Generally, these three steps will remove 60 per cent of the sewage's suspended solids and 35 per cent of its biochemical-oxygen demand.

The three methods that we have just described make up what sanitary engineers call "primary treatment" In many cases, when the sewage is not strong and the stream into which it empties is large and relatively unpolluted, this degree of treatment is considered adequate. In the United States a little more than half of all sewage-treatment plants stop at this point.

Purification by the primary-treatment process can be increased if necessary by the use of chemical coagulants like those used in treating drinking water. The operator adds aluminum sulfate or iron salts to the sewage and produces a floc—a light and loose mass that will settle and take with it a large part of the offending sewage material. Treatment in this manner results in removing from 80 to 90 per cent of the suspended solids and from 65 to 70 per cent of the biochemical-oxygen demand. A plant that uses chemical coagulants is located near the famous Coney Island bathing beach in New York City. In the spring and summer, chemical coagulants are added to purify the sewage more thoroughly and



These large tanks, in a Los Angeles sewage-disposal plant, are used to store the digester gas that is generated during the sludge-digestion process

thus to safeguard the health of swimmers at the beach. In the fall and winter, when there is no swimming, no chemicals are used for purification purposes.

In many cases primary treatment of sewage does not suffice. Even with 85 per cent of the suspended solids removed, the effluent, or outflow, will not be free enough from pollution to avoid trouble if the receiving stream is small or if the sewage is excessively strong Consequently, the sanitary engineer reduces the organic material still remaining in the sewage by a biological process—that is, by causing living organisms to attack it. He begins this process by introducing air into the sewage; this encourages the growth of bacteria which attack the organic matter in the wastes and decompose it quickly.

The intermittent sand filter was one of the first devices to be used in bringing about this biological purification; it is still one of the most effective weapons in the engineer's arsenal. This filter consists of a bed of sand, with a set of underdrains. The sewage flows over the surface of the beds. As it soaks into the sand, slimes alive with bacteria form on the surface and trap virtually all of the offending material It is not at all uncommon to have removals of up to 99 per cent of the suspended solids, a figure that is difficult to approach by any other method utilized for treating sewage.

Unfortunately it is expensive to build and to maintain filtered sand beds. To treat settled sewage, the designer must provide roughly an acre of sand beds for each 80,000 gallons of sewage per day; each acre will care for sewage contributed by from 800 to 1,000 people. The beds must be cleaned periodically by scraping off the mat of solids that forms on the surface. In winter weather the formation of ice makes the operation of the beds difficult. Therefore most designers prefer a more economical method of sewage treatment, even at the sacrifice of a certain amount of purification efficiency.

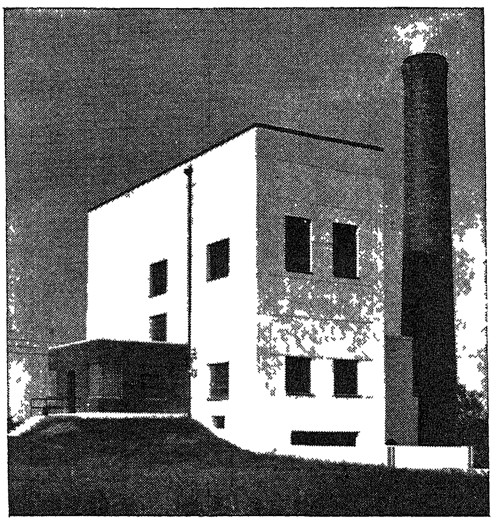
A method that is comparatively economical but quite effective employs what is known as a "trickling filter." This consists of a bed of coarse crushed rock, through which the sewage seeps. Since it goes through at a much faster rate than it would through a sand filter, much less land area is required. Actually the rock does not filter at all; it serves merely as a place for bacteria-laden slimes to grow and for the bacterial army to attack. The rock bed must be coarse enough to contain plenty of air if it is to be effective. With the trickling filter, a secondary settling tank is required, since the slimes slough off periodically. In general practice this secondary sludge is returned to the raw sewage flow as it enters the plant, and it is allowed to settle out in the primary tanks.

Operators may put the sewage through trickling-filter beds at the rate of some 4,000,000 gallons per acre a day, or they may increase this rate to as much as 30,000,000 per acre a day, depending on the nature of the sewage. Treatment can be improved by operating two beds together in stages, or by recirculating a portion of the filtered sewage.

Another good way of supplying biological treatment is through a process known as "activated sludge." In the methods that we just described the biological slimes gather on some medium; in one case it is sand, in the other crushed rocks. In the activated-sludge method, the slimes form within the sewage as air is blown into it; they float around in the sewage, picking up

organic matter and decomposing it. Sludge forms; then the sewage and sludge go to a settling tank where the sludge is allowed to settle out. A part of the sludge is returned to the sewage flow entering the aeration tank; thus the sewage is seeded with living organisms and the growth of the purifying bacteria is hastened. Sewage can be purified by the activated-sludge method so that 90 to 95 per cent of the offending materials, measured either by suspended solids or biochemical-oxygen demand, are removed.

There are other methods of producing activated sludge. One of these brings the



This modern incinerator, at Marreo, Louisiana, disposes effectively of garbage and other refuse.

air in contact with the sewage by means of revolving paddles or brushes; another produces the same effect with a revolving spray that works on the surface of the sewage. In the latter method, the sewage is drawn up a large tube set vertically in the center of the tank. It is thrown violently out to the edge of the tank by the spray mechanism; then it is drawn to the bottom of the tank and recirculated. This method is particularly useful in small installations.

By now the sewage has parted with almost all its solid matter and is no longer a dreadful menace. However, the sanitary engineer sometimes takes a final precautionary measure before the sewage leaves the plant. He sterilizes it with chlorine, which kills the remaining harmful bacteria. As the sewage flows from the treatment plant on its way to the receiving stream, it is sparkling and odorless—a far cry indeed from the turbid and foul-smelling flow that entered the plant. But it is not yet pure enough to drink. If the water of the receiving stream is to be used for drinking purposes, it will have to be carefully treated before it will be judged wholesome enough to go into our water mains. (See Index, under Water Supply.)

The sewage-treatment plant must dispose somehow of the sludge that has accumulated in the settling tanks. It is not considered wise to remove it from the plant without further treatment since it contains decaying organic matter. Consequently steps are taken to render this organic matter harmless, by what is known as anaerobic decomposition — that is, decomposition by means of bacteria that flourish in the absence of oxygen. (The word "anaerobic" is of Greek origin; it means "living without air.")

Anaerobic decomposition takes place in closed sludge-digestion tanks. Here the sludge is "digested" — that is, it is left for about three weeks at a temperature of 90° to 95° Fahrenheit until it is thoroughly decomposed.

Digester gas, the gas that is generated during the sludge-digestion process, is a useful by-product. It is chiefly methane (CH_4); it is the same as the marsh gas generated in stagnant water from decaying leaves and other organic matter. Digester gas is frequently burned in gas-fired boilers that supply heat to keep digesters at the proper temperature and thus allow the bacteria to thrive. This temperature is usually 90° to 95° Fahrenheit. The gas is also used in internal-combustion engines, which generate power for various purposes in the plant. Among other things, these engines operate the blowers that furnish compressed air for the activated-sludge process. They also pump sewage into the plant from conduits that are set deep in the ground.

During World War II the Germans

made extensive use of digester gas to drive cars and trucks, thus supplementing their dwindling supply of gasoline. The British also utilized the gas by compressing it and putting it in certain types of bombs. When these bombs exploded, they produced fires that were extremely hard to extinguish.

Even after digestion the sludge still contains a good deal of water, and it is very bulky. In many of the larger plants on the seacoast, engineers have adopted the practice of putting this sludge on barges, towing it some three or four miles out to sea and then discharging it at a point from which offshore currents will carry it away.

Covered refuse trucks used by the sanitation department of Billings, Montana. Workers can empty containers into these trucks from a low height, thus saving themselves a good deal of hard work.

Of course plants located inland cannot use this method of disposal. Hence it is important for them to reduce the bulk of the sludge as much as possible by means of drying. Small plants dry digested sludge by putting it on beds of coarse sand; the water gradually drains away through the sand. When the moisture content of the sludge drops from more than 95 per cent to about 65 per cent, the sludge can be shoveled up conveniently for disposal. In large plants a mechanical filter is used to drain the water out of the sludge by an extremely effective vacuum arrangement.

The operators of many small plants dispose of digested and filtered sludge by selling it or giving it away to farmers and others, who use it as fertilizer. Certain large plants sell sludge for this purpose on a nation-wide basis. Naturally, this practice recalls the use of night soil as fertilizer in Asiatic lands. Digested sludge, however, is far less dangerous and also far less odorous than raw excretions. Even so, it is not considered advisable to use sludge as fertilizer in growing vegetables that are to be eaten raw unless the sludge has previously lain in the open for six months or so. The best known of American sewage plants that sell sludge as a fertilizer is the one at Milwaukee. Dayton, Ohio, sells much of its sludge to orange growers in Florida. Los Angeles also processes its sludge to be sold for fertilizer. Much of the sludge in west-coast plants goes to fruit orchards and vineyards to enrich the soil.

Certain sewage-disposal plants that cannot dispose of sludge as fertilizer burn it in incinerators. This is an excellent method. The ash is clean and sanitary; furthermore, 95 per cent of the bulk is burned away in the incinerator and the disposal of the ash does not present a difficult problem.

In small installations the Imhoff tank is sometimes used for sewage disposal. This

tank, which was developed by a famous German sanitary engineer, Dr. Karl Imhoff, consists of a two-story arrangement. The sewage settles in the upper compartment; the sludge then drops through a slot into the bottom compartment, where it is allowed to digest. Except for small installations, Imhoff tanks are now being replaced in almost all new plants by settling tanks and separate units for digesting sludge.

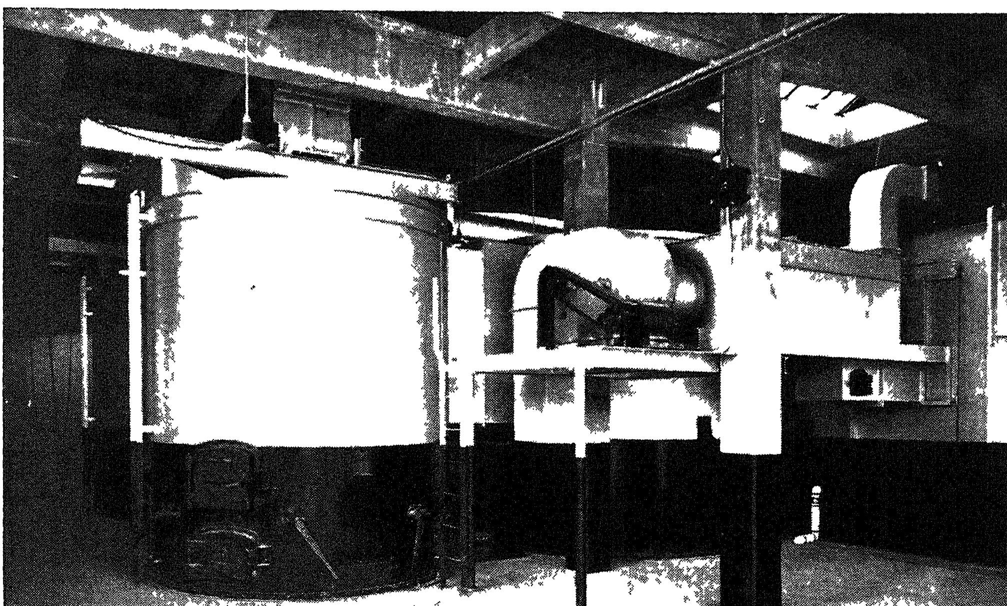
In rural areas where no sewer systems exist, septic tanks are used in small installations, such as homes, in order to treat sewage. A septic tank is one in which the sewage is allowed to settle; at the same time bacteria within the tank digest the sludge. The overflow should be leached away into the soil. The tank is cleaned about once every two or three years.

The operation of septic tanks is not very satisfactory. As the sewage settles, the gas from the digested sludge rises and brings the settled solids to the surface again. The outflow is generally black; it is high in suspended solids and biochemical-oxygen demand. From a sanitary standpoint, the use of a septic tank should be limited to small installations in areas where the soil is porous enough to absorb the sewage that the tank discharges.

DISPOSAL OF OTHER WASTES

We have already pointed out that not all the wastes from our homes and industries can be flushed down sewers. A great deal of garbage, refuse and trash accumulates around our homes. It is said that each person is responsible for about one-half pound of garbage each day and perhaps another two pounds of other rubbish. Prompt removal of these wastes means a cleaner community and less opportunities for flies, lice, rats and other disease-producing nuisances to breed. Not all refuse is collected for reasons of public health Ashes, for example, constitute no health hazard; they are collected so that they will not clutter up the premises.

The nomadic tribes of old were not bothered by the problem of waste collection; they merely cast out their refuse and let the weather destroy it or the birds and beasts eat it. However, as communities grew larger, men came to recognize that they would have to adopt some method or



A set of furnaces in an incinerator. The refuse enters the chute at the top; the ash or residue is discharged into the basement. The fan in the foreground supplies air which helps the burning.

All photos, The American City

Sanitary-fill method of refuse disposal. The tractor is packing down the day's accumulation of garbage and other refuse, which has been dumped into a trench. Later the refuse is covered with dirt.

other of collection and disposal.

In most cities garbage is collected two or three times a week; the balance of the refuse is collected on a weekly basis. In business districts collections often take place daily or even twice a day if necessary Many cities do not require that garbage should be separated from the rest of the refuse; they make a single combined collection of garbage and other wastes.

Formerly garbage collectors used only horse-drawn wagons or open trucks. Trucks like these are still used in many communities. They are unsightly and odorous. They are hard to load, too; generally the garbage collectors must lift the refuse shoulder-high and hand it or toss it to the "top man" on the truck.

Modern collection trucks have eliminated the defects of the old collection system. They are designed so that workers can empty containers from a low height, thus saving themselves a good deal of hard work. The trucks do not require a top man. Some of them have bucket elevators that lift the refuse and carry it into the truck body. Others have low-set hydraulically operated swinging end gates that push each container of refuse into the truck. Still others have a troughlike bucket that is held by two arms mounted on the sides of the truck. When the trough becomes full, the arms lift it to the top of the truck body and dump the refuse in. Most trucks are provided with compacting apparatus for pressing the refuse together, thus making possible a maximum load for each collection trip. In a few cities garbage collectors bring a clean garbage container to the householder and take away the one containing refuse. They then empty the cans at a disposal point and wash them so that they can be exchanged at other homes. This method is sanitary but not very economical.

There are various ways of disposing of garbage and other refuse. Incineration or burning is the most satisfactory method The refuse is burned to an inert and sanitary residue; its bulk is reduced by 90 to 95 per cent. If the incinerators are operated efficiently, no public hazard is involved. Furthermore, the incinerator can be erected at a strategic location inside the city; this greatly reduces hauling costs, which represent the most expensive item in refuse disposal In most incinerators the trucks dump the refuse into a long pit and a traveling crane takes it from there to the furnace. After being burned, the residue drops down to an ash hopper and is hauled away.

Some incinerator plants utilize the heat that is generated when refuse is burned. The heat produces steam in boilers; the steam then serves to heat buildings. The difficulty is that users may require heat at a time when the plant is not in operation. However, this difficulty can be overcome. In Atlanta, Georgia, for example, the heat from the municipal incinerator is utilized in boilers that furnish heat to most of the buildings in the downtown business district. The operation of the incinerator is tied in with that of the local power company; steam can be furnished by the latter's plants when the incinerator is not in operation.

Some communities conduct salvage operations before burning refuse in an incinera-

tor. Materials like paper, broken glass, scrap metal and scrap rubber are almost always in demand, and the sale of such items brings in a certain amount of revenue. Salvage operations reduce the amount of refuse that must be handled by the incinerator as well as the amount of residue that will have to be hauled from it. Salvage is sometimes carried on in connection with other methods of refuse disposal.

In some cities garbage is ground up and then emptied into the sewer system. For convenience, economy and simplicity, this arrangement is hard to surpass. It provides an excellent means of disposing of the large quantities of fruits and vegetables that spoil in warehouse storage. The chief difficulty with this method is that it increases the amount of sewage that the sewage-treatment plant must handle.

Garbage-grinding units for the kitchens of private homes have become quite popular; they greatly simplify the trying task of handling wet garbage. Some officials object to home garbage grinders, claiming that the ground garbage sometimes clogs the sewers. Most competent authorities, however, agree that garbage ground from home units will flow in any sewer that will handle normal sewage.

One of the most economical methods of refuse disposal is "sanitary fill," or "controlled tipping," as it is called in England. In this method garbage and other kinds of refuse are compacted to a dense mass and then covered by two feet of dirt. There are two ways of disposing of garbage by sanitary fill. In the trench method, the operator digs a trench, carefully lays the day's accumulation of garbage in it, packs it down and covers it with dirt. In the area method, the operator deposits the refuse without digging the preliminary trench and then covers each day's deposit with dirt. In this case, naturally, the operator must haul the dirt from some other source.

The advantages of the sanitary-fill method are numerous. It requires a minimum of equipment. Each day's accumulation of refuse is completely covered. Odor and other nuisances are slight; the area that is filled up in this way is generally improved. Last, but not least, sanitary fill does away with unsightly, rat-infested dumps

On the other hand, there are certain disadvantages. The method requires a good deal of land, which will be used up faster than if it were filled with residue from an incinerator. The filled sections may become hard to locate. The system may involve excessive trucking costs. Furthermore, if operators are careless, sanitary fill is anything but sanitary; it may not be much of an improvement over the open-dump method of handling refuse.

Disposing of garbage by feeding it to hogs

Some cities dispose of garbage (but not of other refuse) by feeding it to hogs. This method is the least costly of all; it may even bring in some revenue to the city. However, public-health officials frown on it They point out that hogs that are fed on garbage are apt to become infected with the disease called trichinosis; this disease can be passed on to humans if the pork is not cooked thoroughly. Besides, garbage disposal by hog feeding creates offensive odors and offers a breeding place for flies. Nevertheless this method of garbage disposal is practiced in a number of large cities with acceptable public-health records.

Public-health authorities recommend that the garbage be cooked for thirty minutes at a temperature of at least 212° Fahrenheit before it is fed to the hogs. This cooking eliminates the possibility of trichinosis infection. However, it increases the cost of the operation.

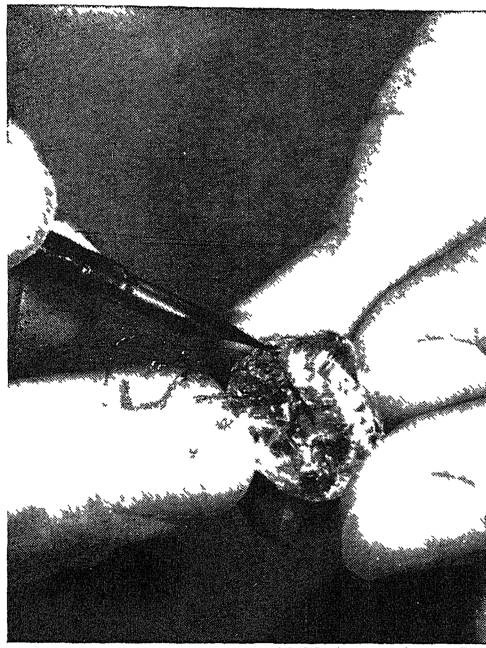
The open-dump method of refuse disposal is the most unsightly, unsanitary and generally unsatisfactory of all. Open dumps are a haven for flies, lice, rats and other vermin; they are a prolific breeding ground for dangerous germs. They are generally allowed to burn constantly. Sometimes the fire gets out of hand and considerable damage is caused to surrounding areas; a number of forest fires have started in this way. All in all, the open dump is a relic of the past; it should become just as extinct, in this modern day and age, as the dinosaur and the dodo.

SYMMETRY UNLIMITED

A Glimpse into the Fascinating World of Crystals

EXQUISITELY fashioned snowflakes, diamonds with glittering facets, the almost perfect cubes of salt grains — these are not random and unrelated forms. They are all fine examples of crystals — bodies with a pattern of flat surfaces that meet at definite angles. The world is full of such crystalline patterns, for almost all inorganic (nonliving) substances in the solid state form crystals. We find them in ice, snow, sugar, salt and sulfur; in metals like gold, silver, copper, iron and mercury; in precious stones like zircon, emerald, topaz and sapphire. Each of these substances generally forms a distinctive crystalline pattern.

Certain nonliving substances, like glass, obsidian and lampblack, do not form crystals. Their inner structure is haphazard and shapeless; so is their outer structure, unless it is modified by the hand of man. We call such solids as these amorphous (from the Greek "without form"). Amorphous solids are not numerous; the great majority of inorganic solids assume some definite crystalline pattern or other.



N. Y. Ayer and Son, Inc.

Marking an uncut diamond with ink to show how it should be cut. Like most inorganic substances, diamonds present a definite crystalline pattern.

THE INNER STRUCTURE

The external differences between crystals are based on the differences in internal structure. The numberless particles of matter within a crystal are arranged in a framework that is called a crystal lattice. Scientists deduced the existence of the lattice many years ago but it was not until X rays were used in the study of solids that definite proof could be obtained. X rays reveal the lattice by causing a definite shadow pattern to be cast when they pass through it. (See Index, under Crystals.)

There are four types of structural units in crystal lattices: (1) small molecules, (2) giant molecules, (3) ions — molecules or atoms with an electrical charge, (4) atoms. (For a description of molecules and atoms see the articles on How Molecules Behave and Inside the Atom in Volume I.)

Crystals made up of small molecules

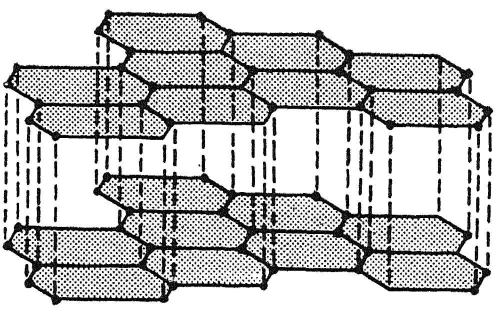
In substances like ice, iodine and solid carbon dioxide (dry ice), the structural units of the crystal lattice are small molecules. These are held together by rather weak forces, partly gravitational and partly electrical. There is much space between the molecules, and the crystals are comparatively light in weight. That is why ice is lighter than liquid water, though both substances are built up of the same H_2O molecules, each consisting of two atoms of hydrogen and one of oxygen.

In general, crystals in which small molecules are the structural units have low melting points; they are good insulators; they are comparatively soft. In some cases the bonds between the molecules are so weak that the solid will change into a gas without first becoming a liquid. This is what happens in the case of dry ice. We call this phenomenon "sublimation."

Crystals made up of giant molecules

Some crystals consist of giant molecules, or macromolecules, as they are sometimes called. These may be built up in one, two or three dimensions.

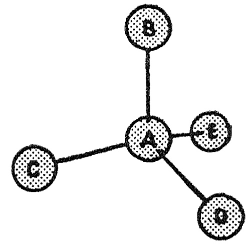
Asbestos is a good example of a substance that forms one-dimensional giant molecules. The asbestos giant molecule consists of a long chain of atoms; this accounts for the fibrous structure of the mineral. The molecules are set side by side; they are linked together by weak forces of attraction.



1. The giant molecules of graphite, made up of carbon atoms, form parallel layers of flat, hexagonal plates, joined together. The bonds between layers are indicated by dotted lines in this diagram.

The giant molecules of graphite, made up entirely of carbon atoms, are two-dimensional; they are joined together in flat hexagonal plates which lie parallel to each other (Figure 1). The bonds between layers, indicated by dotted lines in Figure 1, are weak in comparison with those within the hexagons; hence one layer slips easily over the one beneath it. That is why graphite is one of the best lubricants known.

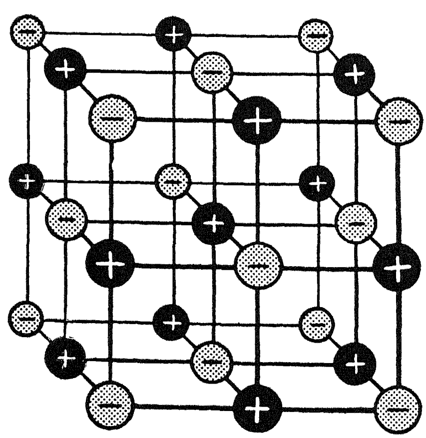
The diamond is a giant molecule built up in three dimensions. Like graphite, it consists exclusively of carbon atoms. Each atom is bonded to four neighboring atoms, which are grouped about it at equal distances. In Figure 2, for example, the carbon atom A is bonded to carbon atoms B, C, D and E. B, C, D and E are each bonded to other atoms in the same way. Since the distances between the atoms in this type of giant molecule are equal, the bonds are of equal strength. The result is a very rigid formation. The diamond is the hardest substance known and it is very difficult to cleave it. It has a high melting point; is a good insulator; is transparent.



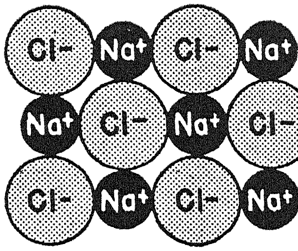
2. How the atoms of giant diamond molecules are grouped. A, B, C, D and E are all carbon atoms.

Crystals made up of ions—electrically charged molecules or atoms

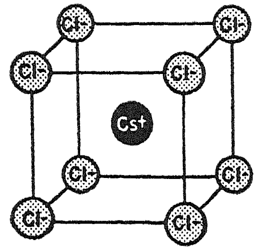
In salts, the unit making up the crystal is an ion, which, as we pointed out, is an electrically charged molecule or atom. Let us recall (see the article on Inside the Atom



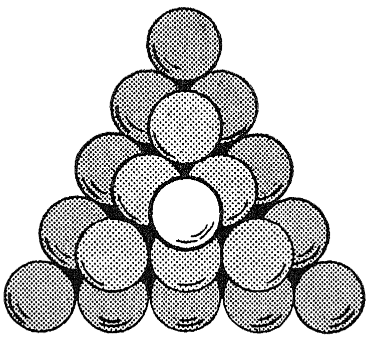
3. How the ions are arranged in the crystal lattice of sodium chloride (table salt). The + circles in the diagram represent positive sodium ions; the — circles represent negative chlorine ions.



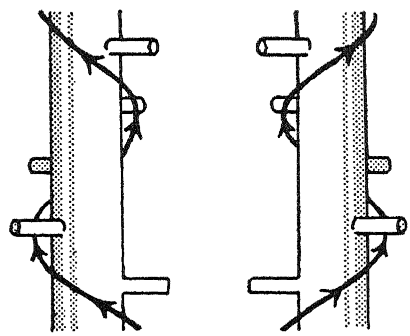
4. Positive sodium ions (Na^+) and negative chlorine ions (Cl^-), closely packed together in the crystal lattice of table salt.



5. The crystal pattern of cesium chloride. The central ion (Cs^+) is equally distant from the others.



6. How atoms (viewed from above) are packed in the crystal lattice of various metals, including iron, lead, gold, silver and aluminum.

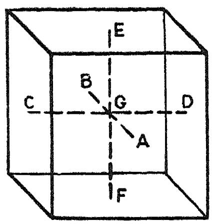


7. Spiral arrangement of the molecules of right-handed and left-handed silicon-dioxide crystals. The right-handed crystal is a "mirror image" of the left-handed one.

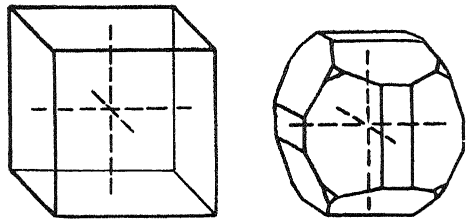
in Volume I) that each atom has a nucleus or central core made up chiefly of protons, each with a positive electrical charge, and neutrons, which have no charge. Around this central core revolve the electrons, each of which has a negative charge. Ordinarily the charge on an atom is neutral; that is to say, there will be as many negative charges as there are positive charges. If an atom loses an electron, it has one excess positive charge; it becomes a positive ion, or cation. If an atom gains an electron, it has one excess negative charge; it becomes a negative ion, or anion.

Let us see what happens when sodium, normally a metal, and chlorine, normally a gas, react to form the solid called sodium chloride (NaCl), which is simply table salt. Each sodium atom transfers an electron to a chlorine atom. As a result, the sodium atom becomes a positive ion since it now has an excess positive charge. Each chlorine atom, on the other hand, acquires a single excess negative charge; it is now a negative ion.

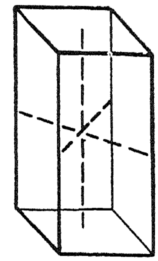
Since ions with unlike charges attract each other, the chlorine ions will attract the sodium ions; but they will hold off the other chlorine ions since ions with like charges repel each other. As a result of the attraction between the oppositely charged particles, each chlorine ion will surround itself with six sodium ions; each sodium ion will surround itself with six chlorine ions. The lattice pattern that results is shown in Figure 3. This pattern will be repeated throughout the crystal. In the drawing we have represented the sodium and chlorine ions as being a considerable distance apart, in order to show the inter-



8. How the three axes of a cube meet.



9. Isometric or cubic system. Left: sodium-chloride crystal; right: pyrite tetrahedrite.



10. Tetragonal system.

lacing pattern clearly. Actually the ions are closely packed together in the crystal lattice, as shown in Figure 4.

This particular arrangement is common when the ions are of about the same size. If the ions vary in size, it may be easier for them to fit together in a lattice of the type shown in Figure 5. Here the central ion is equally distant from eight other ions of opposite charge. The compound cesium chloride ($CsCl$) forms this sort of crystal pattern.

Substances that have the ionic type of lattice have moderate insulating properties and high melting points. They are hard, but they can be split along definite lines.

Crystals made up of atoms which are electrically neutral

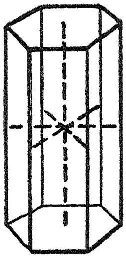
In metals, the atom is the structural unit in the formation of a crystal. The atoms may be thought of as spheres having the same diameter and packed together as closely as possible. To illustrate one arrangement, let us imagine that fifteen billiard balls are racked up to form the base, or foundation layer, of the pyramidal structure shown in Figure 6. Six more are set on top of the first layer of balls; then another ball is placed on the second layer. This shows the closest packing possible in a cube. Iron, lead, gold, silver and aluminum assume this kind of pattern. There are several other arrangements of atoms in metallic crystal lattices. Lattices of this kind are opaque; they have moderate hardness; they have high melting points; they are the best conductors of heat and electricity. These qualities make metals very useful.

The internal structure of a crystal affects its properties

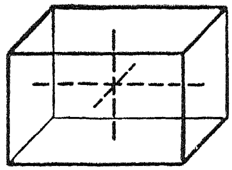
The variations in internal structure shown by different crystals have a direct bearing upon their properties. Different crystals have different lines of cleavage — lines along which they split most readily. They conduct heat at different rates. They react differently to magnetic and electrical forces.

A few crystals, like those of the mineral Iceland spar, have a particularly interesting property — that of allowing only light-waves that vibrate in parallel planes to pass through them. This effect is called plane-polarized light. To understand what is involved, let us try to pass a knife blade between the pages of a closed book. This will be possible only if the knife blade is held parallel to the pages. The book in this case would correspond to the Iceland spar crystal; the knife would correspond to one of the parallel planes in which the light would vibrate.

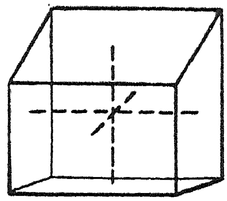
Other crystals have a rather peculiar effect on plane-polarized light. If such light is allowed to pass through a selected crystal of quartz, the plane of polarized light is twisted to the right through an angle. Other quartz crystals will turn the plane to the same angle to the left. Crystals of the first type are called right-handed;



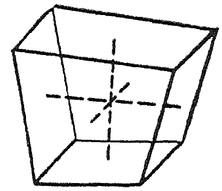
11. Hexagonal system.



12. Orthorhombic system.



13. Monoclinic system.



14. Triclinic system.

those of the second type, left-handed.

X-ray analysis has shown that the molecules are arranged in spirals in such crystals, as shown in the diagram of the right-handed and left-handed silicon dioxide (SiO_2) crystals in Figure 7. These crystal "twins" have the same relation to each other as an object and its reflection in a mirror. They have the same chemical composition; but the structural arrangement that makes one right-handed and the other left-handed also makes their chemical behavior different.

The fact that different crystals will rotate the plane of polarized light in different directions forms a reliable means of identifying certain substances. For example, sugars in solution will rotate the planes of light through different angles; the angle of rotation will identify each sugar in question.

THE EXTERNAL STRUCTURE

Our knowledge of the inner structure of crystals is of comparatively recent date. The outer structure of crystals, however, has been carefully studied for several hundred years. Crystallography, the study of the external characteristics of crystals, is a highly technical subject and it takes years to become expert in it. In the following brief account we shall give some idea of the principles upon which it is based.

Over a hundred years ago scientists adopted a convenient method for classifying crystals on the basis of their external forms. The method is still used to identify minerals occurring in nature as well as chemical compounds of many different kinds. According to this classification, all crystals fall into thirty-two different classes from the viewpoint of external structure. The thirty-two classes, in turn, are grouped in six primary divisions, called crystal systems. These systems are based on the arrangement of the axes — imaginary lines which intersect at a point within the crystal.

To show more clearly what we mean by axes, let us examine a crystal that has the form of a cube (Figure 8). This crystal has six faces, consisting of squares with the same dimensions. If you look carefully at the cube, you will see that there are only three directions in which the edges can run; each axis will be parallel to one of these directions.

Let us drill a hole through the center of the cube on one face, at A, so that it will come out in the middle of the opposite face, at B. This hole, AB, will represent one axis of the cube; it will be parallel to one set of edges. Let us now drill CD and EF in the same way; CD and EF are also axes of the cube. The three axes meet at the point G.

As we shall see, the characteristic axis arrangement is the same for all the crystals within a given system, however simple or complicated they may be. Thus, in Figure 9 the sodium-chloride crystal and the far more complicated pyrite-tetrahedrite crystal belong to the same system because the arrangement of their axes is the same. In the

following description of the six crystal systems, we shall discuss only the simplest form within each group.

A brief account of the six crystal systems

The first of these groups is called the isometric (equal measure) or cubic system (Figure 9). In this system are included the crystals that form cubes or modifications of the cube shape, such as octahedrons (eight-faced solids) and dodecahedrons (twelve-faced solids). These forms have three axes of equal length set at right angles to one another. Among the substances forming isometric crystals are salt, diamond, fluorspar, galena, gold, silver, garnet, iron, copper, lead, mercury, silicon and phosphorus.

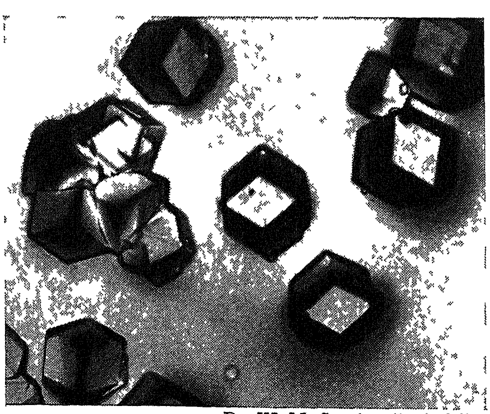
The second group is the tetragonal (four-sided) system. In the simplest form of this system (Figure 10), the four sides are equal rectangles; the top and bottom are equal squares. There are two axes of equal length and a third axis that is different in length; all three axes meet at right angles to one another. Zircon, chalcopyrite, scheelite, wulfenite, boron and tin all form crystals of this general pattern.

The third group is the hexagonal, or six-sided system, illustrated in Figure 11. The crystal shown here has six sides; the top and bottom surfaces are at right angles to these sides. There are three horizontal axes, all in the same plane, set at an angle of sixty degrees to one another. There is also a fourth axis set at right angles to the first three; it may be shorter or longer than the other axes. In the hexagonal system we find most of the gem minerals, including sapphire, ruby, emerald, aquamarine and tourmaline. The crystals of ice and snow fall in this group; so do those of the elements arsenic, antimony and bismuth

The fourth group is the orthorhombic system. In the representative crystal shown in Figure 12, all six faces are rectangles; they meet at right angles. There are three axes of unequal length set at right angles to one another. This system includes sulfur, topaz, chrysoberyl, calamine and benzine.

The fifth group is the monoclinic (one-slant) system. In the form shown in Figure 13, only the sides meet at right angles to one another; the top and bottom surfaces are tilted from the perpendicular Two of the axes meet at right angles, but the third is tilted Gypsum, which is the source of plaster of Paris, belongs to this system; so do kunzite, borax, naphthalene and cane-sugar.

In the sixth crystal system, the triclinic (three-slant), none of the faces meet at right angles; all three axes are inclined at different angles to one another (Figure 14). Turquoise and the feldspars belong to this group.



Dr. W. M. Stanley, Rockefeller Inst. for Med. Res.—from RCA

This remarkable photograph, taken with an electron microscope, shows bushy stunt virus crystals.

It is difficult to find a perfect crystal bounded by absolutely smooth plane faces. Unless the surfaces are formed under exceptionally favorable circumstances, they will show various irregularities; sometimes the crystalline pattern will be so obscure that only the most careful measurements will reveal it. The faces are often marked by grooves, or pits or small outgrowths; sometimes they are curved from strain. Occasionally, too, many small crystals combine erratically. That is why uncut stones so often appear to be dull and valueless; they do not reveal their full beauty until they pass through the hands of the jewelry cutter. Yet occasionally nature produces crystalline masterpieces that are lovelier by far than the most exquisite man-cut gems.

THE CLOUDS OF THE SUN

Revelations Arrived at by Direct Observation and by an Analysis of Sunlight

STORM-CLOUDS THAT RAIN MOLTEN METALS

THE shining disc we see when we look at the sun is not the body of the sun, but only the outer surface of the clouds which completely surround and cover it. This mantle of incandescent clouds, of unknown thickness, is called the "photosphere", or light-sphere. Within it is the central core, containing by far the greatest proportion of the total mass of the sun, though we cannot by any possibility see it. Outside the photosphere, and enveloping it completely, and partly penetrating it is a layer of relatively cooler gases and vapors, called the reversing layer, beyond which is a second mantle, of rosy color, called the "chromosphere", or color-sphere. This consists not of clouds, but of gases, especially of hydrogen, and is invisible except at times of eclipse or to an observer with the spectroscope. Outside the chromosphere, again, is a vast, mysterious, ever-varying system of radial streamers of light, extending outward to prodigious distances This halo, hitherto seen only at eclipse, is known as the "corona", or crown. Reckoning from within outward, therefore, we have the nucleus, the photosphere, the reversing layer, the chromosphere and the corona; and we shall consider them in that order.

The central nucleus, as we have seen in earlier chapters, is a mass of intensely heated gases under enormous pressure. The temperature and the pressure alike are greater than any we can well imagine, and together are supposed to produce a condition for which laboratory experiments can show no analogy. The temperature is so high that even under the pressures to which they are there subjected these gases do not liquefy; and, enormous as the temperature is at the surface of the sun's globe, it must increase to an incomparably higher degree towards the center. The pressure is such that the mixed gases become denser than water, attaining a density considerably greater than 1.42, which is the mean density of the sun; and inasmuch as the viscosity, or adhesive power, of gases is known to increase in proportion to the temperature, it is believed that the gaseous material of the sun's nucleus has a consistency somewhat like that of putty. Yet, with all this density and clinging stickiness the sun's core never ceases to be gaseous Though this state of things is barely imaginable, it is not on that account at all impossible. Yet it must be borne in mind that there neither has been, nor, so far as we know, is ever likely to be, any direct observation of the nucleus of the sun. All conclusions with regard to it are merely inferential.

The photosphere, or mantle of incandescent material forming the visible surface of the sun, is thought by many to consist of actual clouds with a considerable likeness to those of the earth. According to this view, just as our clouds are formed by the condensation of vapor, by cooling, into minute droplets which float in the atmosphere, so the sun-clouds are formed by the condensation of metallic vapors, by cooling, into minute droplets and crystals, that float in a similar manner in the gaseous solar atmosphere.

How the sun clouds drop showers of molten metal into the blazing abysses

In the same way as our clouds do not in general extend over us in an unbroken roof, but are separated from one another and make a kind of pattern in the sky, so it is with the sun-clouds. They, too, give a distinct characteristic texture or pattern to the visible surface of the sun. As our clouds drift with the winds, are whirled in cyclones, and are drawn out into long streamers, so are the sun-clouds. And it is not unreasonable to believe that just as our clouds fall in rain, so the clouds of the sun drop showers and cataracts of molten metal into the blazing abysses below them.

The only really serious difficulty against this view is the very high temperature of the photosphere which would exclude the presence of any solid or liquid except perhaps in the highest and relatively cooler layers, and in the sun-spots.

How telescopes and telescopic photography are used in studying the sun

The sun's surface is studied by means of telescopes constructed in such a way as to reduce the light to a degree comfortable for the eye, and by photography in conjunction with telescopes. When seen by either means, the photosphere presents a remarkably granular appearance. Innumerable bright, irregular grains or flecks are closely strewn upon a less brilliant background, and are irregularly grouped in clusters and curved lines. The general impression has been compared to that given by snowflakes scattered on a gray cloth. Under the highest telescopic power and in exceptionally clear states of the earth's atmosphere, these grains or flecks have been seen to consist of yet smaller granules closely grouped together. These grains and granules have diameters, roughly speaking, of 1000 and 100 miles respectively, and are probably the outer ends of vertical columns of clouds or ascending currents of highly incandescent vapors; for where the solar atmosphere is much perturbed, as in the neighborhood of sun-spots, the grains are drawn out into long, irregular, parallel streaks and filaments.

Some of the changes which photography registers in the sun

Even in a perfect photograph this granulation is sharply defined only over limited areas, separated by an irregular network of patches in which the solar surface appears misty, confused and non-granulated, very much as if it had been out of focus, or as if the photographic plate had in some other way been blurred by a network of streaks. This "photospheric reticulation" (*i.e*, network of the photosphere) changes in such a way that although two photographs taken within a few moments of one another show the same reticulation, the form of the network is found to have changed if an hour or more has elapsed between the first photograph and the second. This local indistinctness, obliterating the granular structure, is probably due to violent motions of the sun's atmosphere, preventing any clear vision through the regions in which they may happen to occur; and the changes of reticulation will in that case be due to the motion of atmospheric storms across the surface of the sun. "The simple fact is," according to the late Professor C. A. Young, "that we are looking down upon the granules and other features of the sun's surface, not through an atmosphere shallow, cool and quiet like the earth's, but through an envelope of matter, partly gaseous and partly, perhaps, pulverulent or smoke-like, many thousand miles in depth, always profoundly and violently agitated."

To this smoky character of the photospheric atmosphere is ascribed the comparative darkness of the background against which the incandescent clouds are seen. The metals rising from the interior in the form of vapor, in mighty ascending currents, are first condensed into incandescent droplets or crystals, and so give rise to the luminous clouds; and then, becoming further cooled as they radiate their heat into space, lose their incandescence and form a smoke or fog which sinks downward between the clouds, until it reaches a level at which the temperature is sufficient to convert it again into vapors of the metals.

Why the light of the sun appears to us to be more brilliant in the middle

The same smoke, pervading the atmosphere around and above the brilliant clouds, accounts for the remarkable absorption of light at the edge of the sun's disc, or, as it is usually called, at the "limb" of the sun. It is obvious that, since the shining surface of the sun is a sphere, the light which comes to us from near the edge of the apparent disc must pass through a greater thickness of the overlying solar atmosphere than light which comes to us from the center of the disc. From the diminution of the sun's brilliancy towards its edge, which is very evident when the sun is viewed through a smoked glass or through an evening haze, it is reasonable to infer that the atmosphere of the sun intercepts a considerable proportion of its light.

By means of the spectroscope, it is possible to determine the chemical elements present in the outer layers of the solar atmosphere.

A description of this instrument in its various forms, and of the results gained by it, appears in another part of this work, and need not be repeated here. It is enough if we understand that white light consists of a blend of lights of all colors, from red, through orange, yellow, green and blue, to violet, with every intermediate shade of color; that every particular shade of color is given by light-waves of a definite length, the waves of red light being the longest and those of violet light the shortest; and that there is an indefinitely extended series of wave-lengths longer than those of red light, and similarly and indefinitely extended series of wave-lengths shorter than those of violet light. The range of color from red to violet marks, not the limit of the longest and shortest light-waves, but the limit, in each direction, of human vision.

Now, if, by means of the spectroscope, a ray of white light is passed through a narrow vertical slit, in order to give it the definite shape of a thin ribbon stretched horizontally with its edges vertical, and if it then passes through a prism of glass, the innumerable colored lights constituting the white light are separated out by the prism, according to their wave-lengths. So the light which entered the prism as a single white ribbon leaves it as a series of innumerable divergent colored ribbons. But if the ribbon of light entering the prism, instead of being white and containing all wave-lengths, consists of light containing, let us say, only three or four definite wave-lengths, it will emerge from the prism as three or four definite divergent ribbons. In the spectroscope the ends of these ribbons of light come into view side by side as a row of vertical colored lines, or colored images of the slit, extending from deep red at the left hand to violet at the right. In the spectrum of white light these vertical colored lines, however narrow the slit is made, touch and overlap, forming a continuous spectrum. We may compare the spectrum to a fence of vertical laths. In a continuous spectrum the laths touch and overlap. In other spectra, however, there are laths, many or few, here and there; and as every part of the fence is accurately mapped, the spectrum produced by any special source of light can be definitely recognized.

The use of the different spectra in examining the sun

There are certain principles, of great importance, which reveal the *nature* of a distant source of light. Thus, a continuous spectrum, comparable to a fence in which all the laths are present, comes from an incandescent solid, or from an incandescent liquid, or from an incandescent gas under great pressure; that is to say, such bodies, whatever be their chemical composition, when heated so as to become self-luminous, give out light of all wave-lengths within the range of vision. A discontinuous spectrum, on the other hand, comparable to a fence from which many or most of the laths are absent, comes from an incandescent gas that is not under great pressure, or from a mixture of such gases. That is to say, any material in the gaseous condition and uncompressed, whether it be one of the bodies

we know on earth as a gas, or whether it be a metal heated to such a degree as to become a luminous vapor, gives out only certain lights of definite wave-lengths, and so produces a spectrum characteristic of that particular gas or vapor. This spectrum consists of bright lines and bright bands, at certain definite parts of the whole range of the spectrum

How the story of the chemistry of the sun is read in its spectrum

But besides the continuous spectrum and the discontinuous spectrum of bright lines and bands, there is a third kind of spectrum, which for the study of the chemistry of the sun is the most important of the three. This is a discontinuous spectrum of dark lines, superimposed upon the continuous spectrum of all the colors. It depends upon the remarkable fact that any gas, interposed between an incandescent source of light and the spectroscope, absorbs exactly those kinds of light that would constitute its own bright-line spectrum if itself were to be incandescent. The intervening non-luminous gas throws dark lines upon the spectrum, exactly in the places where it would throw bright lines if itself were the source of light. Such a spectrum is said to be a "reversed spectrum".

In consequence of this principle, it is possible to identify the comparatively non-luminous gases and metallic vapors present in the atmosphere of the sun, around and above the photosphere. The underlying photosphere gives a continuous spectrum, but each of the intervening gases and metallic vapors in the solar atmosphere absorbs light of certain definite wave-lengths.

The solar spectrum, therefore, as we receive it, is a continuous spectrum crossed by a vast number of dark lines. These dark lines tell the story of the chemistry of the sun's atmosphere.

We have spoken of these intervening gases as *comparatively* non-luminous, because they are non-luminous only in comparison with the far greater brilliancy of the photosphere. They are actually luminous, though in a far lesser degree. This is beautifully seen in eclipses of the sun, when the solar atmosphere shows its own bright-line spectrum for one brief moment before the moon, which has already eclipsed the sun's disc, eclipses its atmosphere also. For that brief moment the sun's atmosphere is seen to act, not as a veil throwing a dark-line spectrum, but as a source of light throwing a bright-line spectrum This momentary spectrum is called the "flash" spectrum, and was first observed by Young in the total eclipse of 1870.

By means of the dark-line spectrum it has been proved that the sun contains a large number of the elements familiar to us on earth. The recent discovery of new lines in the spectrum of the sun's corona suggested a new element, *coronium.* However, studies by D. H. Menzel and J. C. Boyce seem to show that these coronal lines are due to oxygen atoms high in the solar atmosphere. These atoms are in peculiar states of excitation and hence give a spectrum which is not common to oxygen in a normal state.

Does the fierce heat of the sun ionize the elements and change their spectra?

To explain the apparent absence, in the photosphere, of certain common terrestrial elements, two theories were given. One theory holds that the lines of certain elements in the sun are cloaked or entirely suppressed by the presence of the other elements. The second theory is based upon the fact that certain elements are known, under laboratory conditions, to give different spectra according as they are subjected to different treatment; and it is reasonably enough suggested that in the solar heat the spectra of some of our familiar elements may be so altered, particularly by the ionization of these elements, as to escape recognition. A third view, originated by Sir Norman Lockyer, but now almost universally discarded, is to the effect that these substances which the spectroscope fails to find in the solar atmosphere are not really elementary substances, but are there split up into their constituent elements, having separate spectra which are unknown to us.

Strange appearances on the sun's atmospheric covering or photosphere

We have seen that the visible surface of the sun has a granular appearance, indicating a complex structure of the photospheric shell. Nothing is known as to the lower limits of this shell, nor whether it is separated from the sun's nucleus by any definite surface. The upper or outer surface of the photosphere is, however, very definite, as may be seen from the sharply cut edge of the sun's disc.

Yet there are irregularities of two kinds on the surface of the photosphere, both of great interest. In some parts the luminous clouds, which generally lie in a more or less level plain, rise to form great mountains and ridges of incandescent cloud-stuff, appearing to the observer as patches and streaks greatly exceeding in brightness the surrounding regions. In other parts the brilliant surface of the photosphere may be seen to be torn apart, or deeply depressed in the smoky atmosphere, so as to produce patches that are quite dark as compared with the surrounding surface. The patches of brightness are known as faculæ — that is to say, "little torches"; the dark patches are known as sun-spots (see page 1787).

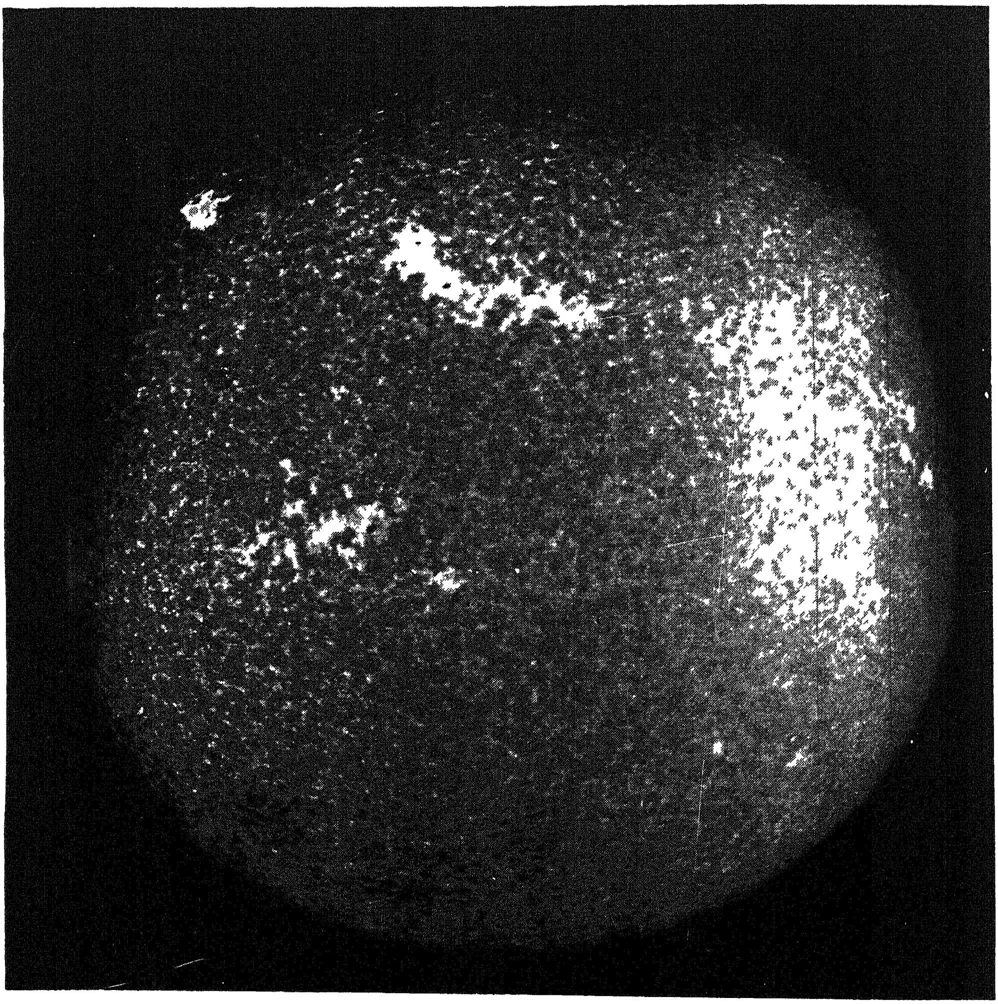
The flaring brightness of the sun's surface that makes other brightness dark

Spectroscopic methods have shown that the faculæ are formed in every part of the sun's surface, though they are far less numerous towards the poles than elsewhere, and are especially numerous in the vicinity of sun-spots. However, to an observer with a telescope, faculæ are visible in the regions of diminished illumination towards the edge of the disc, but are invisible in the more brilliant central regions of the image. The reason for this difference is found in the fact that though they appear only like little patches of extra brilliancy, the faculæ are vast elevations of the photospheric cloud surface, often many thousand miles in diameter, and rising to great heights in the solar atmosphere. This atmosphere, as we have seen, absorbs a considerable portion of the light from the photosphere, but does so to a very much greater degree towards the edge of the disc than towards its center, because light coming from the edge has to penetrate a much greater thickness of atmosphere than light coming from the center. Inasmuch as the incandescent faculæ rise far through the solar atmosphere, and may in some cases even extend above it, their light suffers little, or in extreme cases no, diminution from the atmospheric veil, and is consequently nearly or quite as bright towards the edge of the sun's disc as it is in the central area of the disc. Towards the edge of the disc, however, the general surface of the sun, forming the background against which they are seen, is far less brilliant, and the faculæ are consequently far more conspicuous than in the center of the disc, where, owing to the comparative thinness of the atmospheric veil, there is no great difference in brightness between the faculæ and their surroundings.

That the faculæ are eminences rising far above the general surface of the photosphere is proved by the sight of them sometimes in profile at the edge of the sun's disc, where they appear as minute and very brilliant projections of the outline. The spectroscopic evidence to the same effect is very striking, and has been made the means of showing the existence of faculæ in the central regions of the disc. It will be remembered that the gases of the solar atmosphere, though enormously hot according to all terrestrial standards, are relatively cool as compared with the photosphere which lies below them, and therefore act spectroscopically, not as themselves an incandescent source of light producing a bright-line spectrum, but as gases interposed between the source of light and the spectroscope, producing a reversed spectrum of dark lines. From certain patches of the sun's surface, however — namely, from the faculæ — these gases and metallic vapors, or some of them, give a bright-line instead of a dark-line spectrum, proving that in such places the hotter substances from below have been projected upwards through the comparatively cooler atmosphere.

"Suppose, for instance," says Sir Robert Ball, "a prominence consisting of a vast mass of glowing calcium vapor is projected to such an elevation in the sun's atmosphere that the brilliance which the incandescent vapor pours into the calcium lines more than compensates for the absorption due to the cooler calcium vapor outside, then we have what is called a reversal of those particular spectral lines. Sometimes the singular spectacle is presented which is known to spectroscopists as a double reversal; in this case the ordinary dark line is filled with a rather broad band of luminosity, and down the center of the bright band a fine dark line is found to be inserted. In this case we interpret the double reversal to be an indication of the presence of a volume of glowing gas overlaid by a not very copious atmosphere of the same gas in a cool state."

Photographs taken of the sun by means of the spectroheliograph, which admits light belonging only to one part of the spectrum, show faculæ all over the disc of the sun; and from a series of photographs of this kind it has been shown that in general the faculæ change their shape very slowly, and often remain unaltered from day to day. In the vicinity of sun-spots, however, they are subject to violent changes.



THE SURFACE OF THE SUN WITH THE PATCHES OF EXCEPTIONAL BRIGHTNESS
This spectroheliograph was taken at the Yerkes Observatory on April 27, 1903.

Sun-spots are in several respects the most striking features of the surface of the sun. They are sometimes so large as to be seen easily with the unassisted eye, and have therefore been known for many centuries, though until comparatively recently they were taken to be planets passing between the earth and the sun. It was not until the advent of the telescope early in the seventeenth century that their true nature as dark spots on the solar surface was clearly recognized. They have been much studied during the last fifty years, but astronomers are not yet fully agreed with regard to their nature and causes.

A typical sun-spot has the appearance of a more or less circular aperture in the incandescent photosphere. Its center is an apparently very dark area, like the mouth of a pit, called the "umbra"; and round this central black spot is a moderately dark border, called the "penumbra", consisting of irregular, wavy streamers of cloud grouped more or less radially. The umbra is not really dark, but is actually very brilliant; it appears dark only in contrast to the surrounding regions of the blazing photosphere. Its area is often pierced by a few small round spots much darker than itself, and these are supposed to represent pits penetrating to the deeper abysses of the sun. The penumbra apparently consists of incandescent clouds drifting into the umbra, and seems brighter at its inner edge, next the umbra, than at its outer rim, next the unbroken surface of the photosphere. The tips of the clouds of the penumbra break off and melt away in the umbra.

Are the sun-spots atmospheric whirlpools around holes in the sun's cloud-mantle?

Sun-spots are not by any means always circular, but assume a great variety of forms. some of them extremely irregular. The faculæ, or "little torches", described above, are numerous in their neighborhood, indicating, like the sun-spots themselves, violent perturbations of the solar atmosphere. Individual spots arise as minute specks, grow in size, change their shapes, often divide into two or more spots thus forming a group, and, after persisting for a few days, weeks or months finally disappear. Most of them last about eight or ten weeks, but sun-spots have been known to remain for a year, and even for eighteen months.

Some spots are plainly depressions in the surface of the photosphere, but their appearance varies greatly and no general conclusion can be drawn from the conflicting testimony of different observers as to the surface level of sun-spot areas.

The size and distribution of sun-spots over the sun's surface

Sun-spots vary greatly in size, one of the largest on record having a diameter of 143,000 miles. This, however, is very exceptional, and one having a diameter of 20,000 miles is considered fairly large.

Sun-spots are not equally distributed over the surface of the sun, but occur chiefly in two zones, one in the northern hemisphere and the other in the southern hemisphere, at equal distances from the equator. The poles and the equator are nearly free from spots, and by far the greater number appear between the latitudes of 10 degrees and 35 degrees north and south. Sometimes the northern hemisphere, and at other times the southern, is more affected by spots than the other; for example, a period of forty years has been known to pass without any appearing on the northern hemisphere at all.

Sun-spots have movements of their own; thus, a small proportion of them rotate in one direction or in the other, and the two spots formed by the division of a single spot are sometimes seen to fly apart with great velocity. In general, however, the sun-spots move with the surface of the sun, and are consequently useful in determining the direction of the solar axis and the speed of the sun's rotation By observations of the movements of sun-spots the remarkable fact was discovered that while a point on the sun's equator makes a complete revolution in little over twenty-four days, a point at 50 degrees north latitude takes over twenty-seven days for one revolution. That is to say, the sun, or at least the photosphere, does not rotate in one piece as a solid body would do,

but the equatorial regions rotate considerably faster than the regions about the poles. Various theories have been brought forward to account for this fact, but none of them has proved altogether satisfactory.

Some apparent influences of sun-spots on the atmospheric conditions of the earth

The frequency of sun-spots is greater in one year than in another; and it has been definitely ascertained that the times when there are fewest and the times when there are most alternate with considerable regularity and at fairly constant intervals. The average interval between one time of maximum activity and the next is rather over eleven years. In this period about six and a half years show declining activity and the following four and a half years show increasing activity. The periodic rise and fall of the frequency of sun-spots is unquestionably related to a periodic increase and decrease of disturbances in the magnetism of the earth, as shown, for instance, in particularly brilliant displays of the aurora borealis.

From this relationship it was for a long time supposed that sun-spots were of a magnetic character, but it was not until the application of the spectroscope to sun-spot investigation, especially by Hale in 1908, that direct evidence of the magnetic fields in sun-spots was secured and the polarity and strength of their fields were determined.

Thus the magnetic influence of sun-spots is thoroughly established but it is not so certain that a clear connection can be made out between the periods of sun-spot activity, on the one hand, and the condition of our weather, the value of our crops, and the state of our trade, on the other hand. A great deal of ingenuity has been devoted to showing a connection of that kind between solar changes and terrestrial affairs, and any positive knowledge, for instance, of the influence of sun-spots on crops, and indirectly on credit, would be highly valuable. Men of great authority have supported such a theory, but others, with not less authority, have hitherto rejected it.

The arguments for and against the whirlpool theory of sun-spots

The nature and causes of sun-spots are not yet fully understood. Many elaborate theories have attempted to account for their origin, but of these there remain only two which at present receive any considerable support. One, brought forward by the French astronomer, Hervé Faye, and later confirmed with some modifications by a large mass of spectroscopic work done at Mount Wilson and described by Charles G. Abbot in his notable work on "The Sun", regards a sun-spot as caused by a vast vortical movement in the sun's atmosphere, of the same kind as our whirlwinds and cyclones, only on a prodigiously larger scale. It is supposed that these vortical whirls create conical tunnels in the mass of the photosphere; this whirling motion is accompanied by an expansion and consequent cooling of the materials involved, so that the temperature falls perhaps as much as 2000° C. with a corresponding diminution of brilliancy.

Other suggested explanations in an unended and baffling controversy

The other theory, originated by Secchi regards the sun-spots as formed by masses of metallic vapors which, after being thrown up by eruptions in the sun's surface, have become relatively cool in the upper regions of the atmosphere, and then, descending upon the surface of incandescent clouds, have formed the depressions in the luminous surface we know as sun-spots.

This theory was the one favored by Professor Young who wrote as follows: "It may be that the spots are depressions in the photospheric level, caused not directly by the pressure of the erupted materials from above, but by the *diminution of upward pressure* from below, in consequence of eruptions in the neighborhood, the spots thus being, so to speak, *sinks* in the photosphere." Possibly it is safest to suppose that no simple theory will ever account for these very complex phenomena.

THE WONDERS OF WATER

Where It Comes from, How It Was Made, and Why It Varies in Its Composition

TESTING THE DIFFERENT SEA WATERS

IT is an amazing thing that the hard, stony earth should be encircled by that curious collection of nimble gases known as the atmosphere. Almost more amazing is it that the world should carry its wonderful burden of that substance known as "water", and should carry it in three shapes — as vapor, as liquid and as solid. Practically, all other things about the surface of the earth are solid, but the atmosphere remains gaseous, and the water hesitates in an unstable condition of betwixt and between.

The temperature of the earth has fallen a good many thousand degrees since the crust of the earth was molten, and now a fall of a few degrees more would freeze the ocean. A further fall of a few degrees, and a sea of liquid air would cover the frozen ocean. A still further fall, and everything in the world would be solid. The difference between a world with balmy breezes and rolling seas, and a world with neither atmosphere nor ocean, is only the difference of a few degrees Fahrenheit. Fortunate it is that air and water are the last to solidify; that they were there to *be* last, for without them the world would be a shriveled, dry mummy, like the moon.

Water is a particularly surprising substance. It is a compound of two gases, hydrogen and oxygen, and it is a compound which does not form spontaneously. How, then, does it happen to occur in such large quantities? It is true that all the water on the world only wets the earth in proportion to its size as an apple is wet by a misty rain, but it required a vast amount of the gases to produce even so little moisture. How, then, is there so much of it? Where did it come from? When did it come? These are interesting, difficult, inevitable questions.

One thing is certain: that is, that when the crust of the earth was hotter, any water there might be then must have existed in the form of vapor. The great basins of liquid water are the ocean beds, but until the crust of the earth had cooled for thousands of years the ocean beds could have held water no better than a red-hot frying-pan. Were, then, all the oceans once up in the air? Did the sea-water and the polar ice, and all other water, originally form a huge atmosphere of vapor? No; we cannot believe that. The sea as vapor would have hundreds of times its present volume, would have formed an atmosphere thousands of miles high, and the earth could not have retained such a voluminous and volatile atmosphere. Even if the earth could by any possibility have held such a vast atmosphere of water-vapor, we should still have to explain where this vapor came from, and how the compound was formed.

We surmount the difficulties and obtain a plausible answer to the problem only by assuming, as we assumed in the case of the atmospheric gases proper, that the water-vapor was formed not all at once, but by degrees, so that at no time did the earth's atmosphere contain more water-vapor than the earth's gravitative power could grip. Good! But *how* was the water-vapor gradually formed? How was this marvelous compound of hydrogen and oxygen produced?

There are two or three possible sources of water-vapor. In the laboratory water may be made by passing an electric spark through a mixture of hydrogen and oxygen. Now, it is probable that, in the early volcanic days of the earth's existence, hydrogen was belched forth by volcanoes in great quantities; and it is probable that in the same early days lightning-storms were more violent and more frequent than now, and so it is quite likely that the lightning, as it flashed through the atmosphere, combined oxygen and hydrogen into water. So much water, then, would be formed in the atmosphere by lightning, and would gradually condense as opportunity offered. That would be a worthy birth of this wonderful substance — to the flash of lightning and the roar of thunder, from the flames of volcanoes

But a more important factory of water would be the bowels of the earth, and from this factory water would be sent to the surface ready-made. Meteorites contain, among other gases, hydrogen; and there can be no doubt that there was hydrogen in solution in the molten crust of the earth, and that a considerable quantity of hydrogen must have been stored subterraneously.

How in all likelihood the ancient volcanoes threw up the oceans

Under the right conditions of temperature and pressure the hydrogen would take oxygen from the ferric oxide of the earth's crust, or join any free oxygen it could find, and form water, and this water would reach the surface of the earth by means of hot springs, and geysers, and volcanoes. Probably volcanic steam is the chief source of water, and possibly alone suffices to account for all the water in the world. What a pretty paradox is this — water, the extinguisher of fire, made by fiery volcanoes!

The amount of steam discharged by a volcano is surprisingly large; from one subsidiary cone of Mt. Etna, according to careful estimation, in 100 days, 460,000,000 gallons of water were blown out as steam. In the early days of the world volcanoes were probably much more numerous, and volcanic action was probably much more vigorous. It is noticeable that all the great seas are ringed by volcanoes; and how many volcanoes may have formerly been spouting and snorting in the bed of ocean, who can say? Certainly the volcanic islands in the Pacific suggest violent volcanic action

The story told in corroboration by volcanic dust flooring the ocean beds

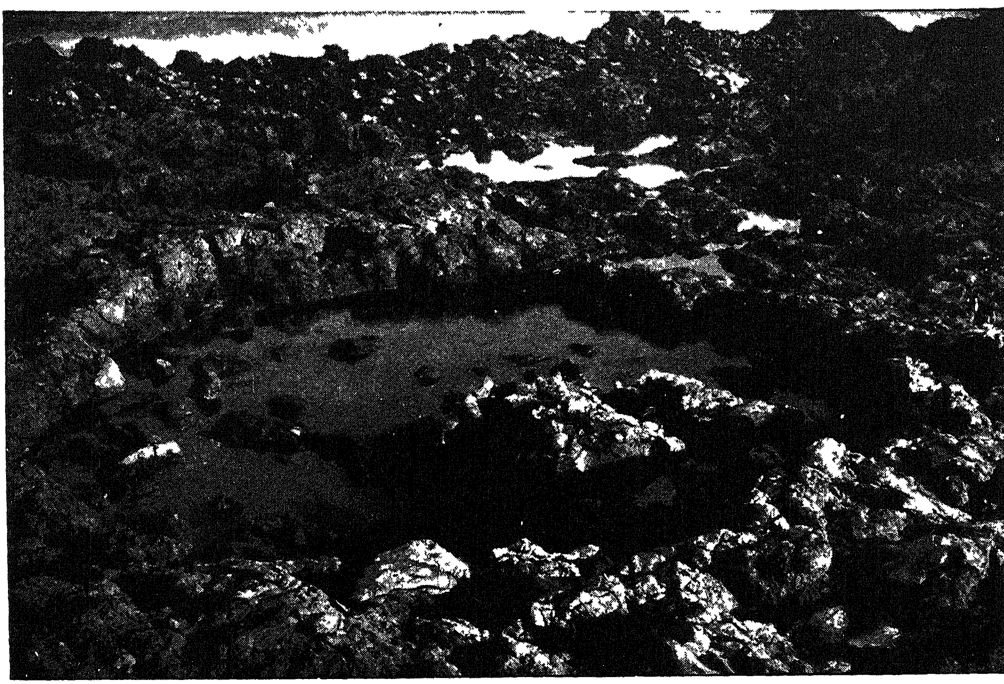
Suggestive, too, of volcanic action is the volcanic dust found everywhere in the abysmal depths of the sea. It is true that this dust is usually supposed to have sunk through the water; but why, then, is it found only or mainly in the deep sea? It is quite as likely that it is the product of the same submarine volcanoes whose steam condensed as ocean water. Altogether it is not difficult to believe that, in one way or another, water is of volcanic parentage.

Having now found a source of the water of the earth, let us look at some of its properties. A most paradoxical substance is water. It is a compound of oxygen, a gas which supports combustion, and of hydrogen, a gas which burns, and yet it will not support combustion, and will not burn. Again, both oxygen and hydrogen are most difficult to liquefy and solidify, and yet at ordinary temperatures water changes from liquid to solid, from solid to liquid, with great facility. As vapor we find it constantly in the air; as snow and ice we find it wherever the temperature falls to 32° F. or below; and as liquid we find it, at some time or other, in almost every part of the world. Whether as gas, liquid or solid, it plays a most important rôle in the economy of nature.

One of the most unique characters of water is its capacity for heat. It has greater thermal capacity than any of the other common known substances, the thermal capacity of a substance being the number of heat units required to raise the temperature of unit weight of the substance one degree. On the same fire, under the same conditions, an ounce of mercury will grow as hot in half a minute as an ounce of water will grow in an hour. As a consequence of its heat capacity, hot water takes a long time to grow cold; and this and some other related properties of water have an important bearing on the question of climate.

Wherever land is surrounded by sea, or near the sea, the climate tends to be more equable than inland. Not only does the vapor the sea gives to the air act as a parasol by day, shielding the earth from the hot sun, and as a blanket at night, returning to the earth the heat that would otherwise radiate away, but the thermal capacity of water which we have mentioned has an even more marked effect in preserving an equable temperature. For since the sea requires much more heat to warm it than the land, it is like a cool wet cloth laid over the land sweltering with heat; again, since it stores up great amounts of heat, it gives this to the land if the land be cooler than the sea. A pound weight of water requires as much heat as four pounds of air to raise its temperature one degree; and thus one pound of water can heat four pounds of air one degree at an expense of only one degree of its temperature. Also, air is seven hundred and seventy times as light as water, and hence one cubic foot of water, by surrendering sufficient heat to lower its temperature one degree, can raise through one degree the temperature of no less than three thousand and eighty cubic feet of air. When we come to talk of climate we will return to this topic.

It requires a great deal of heat to raise the temperature of water from 32 degrees F. (freezing-point) to 212 degrees F. (boiling-point), but in order to convert it into vapor a great excess of heat is required over and above the heat needed to make it boil. To raise the temperature of one pound of water from 32 degrees F. to 212 degrees F. requires 180 times as much heat as is required to raise its temperature one degree (*i.e.*, 180 so-called "heat-units" are required); but to convert the water at 212 degrees F. into steam at 212 degrees F. requires no less than 967 heat-units, or more than five times as much as is required to heat the water to boiling-point from freezing-point. All this heat applied to the water to change it to steam does not raise the temperature of the steam, and it is therefore called "latent" heat. The latent heat in the steam becomes manifest again when the steam is condensed; and one pound of steam passed into five pounds of water at 32 degrees F. will, as it condenses, give off enough latent heat to raise the whole five pounds of water to 212 degrees F.



CRATER ON A VOLCANIC ISLAND THAT APPEARED NEAR TRINIDAD IN NOVEMBER, 1911

Suppose, now, heat is applied to ice, what happens? We find that if the ice is at zero F. each heat-unit will raise it 2 degrees, so that 16 heat-units will raise it to 32 degrees F. Ice is therefore twice as easily heated as water. But to convert the one pound of ice at 32 degrees F. into water at the same temperature no less than 144 additional heat-units are required. Here, again, the heat does not change temperature, but is *latent;* and here, again, the latent heat will become manifest if the water again freezes This alternate absorption and release of heat by water as it changes its state is one of its most characteristic features, and fits it for the part it plays in transmitting and regulating natural energy.

U. S Coast Guard

A CUTTER NOSING ITS WAY THROUGH ICE FLOES

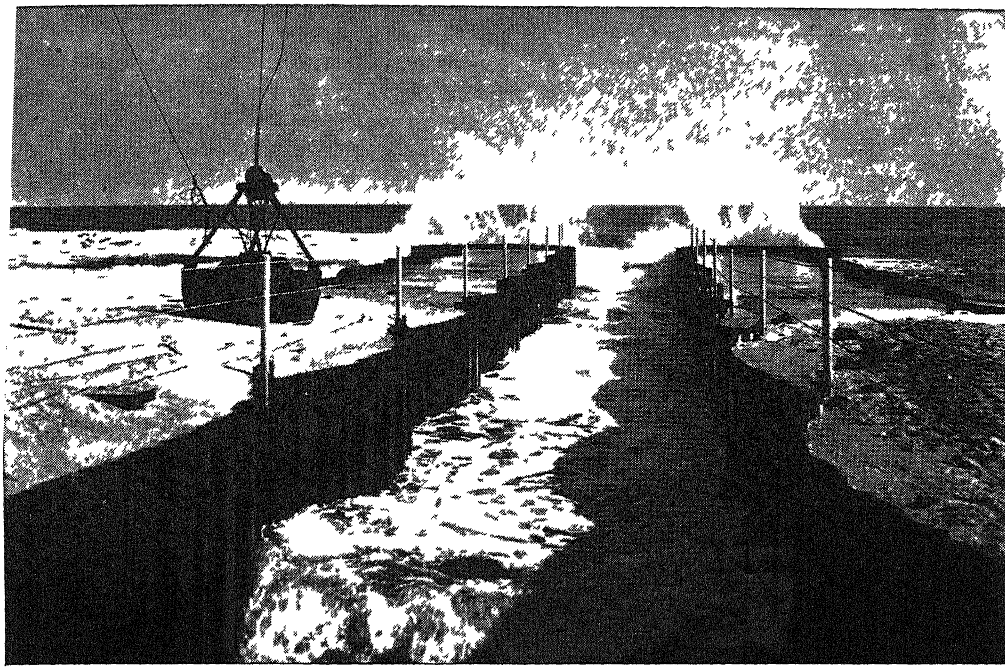
A very remarkable anomaly of water is that its volume at 32 degrees F. is 8 per cent less than the volume of the same weight of ice. Thus water in freezing expands; and if we examine the behavior of water as it cools down towards freezing-point we find that down to 39 degrees F. it contracts as it cools, just like ordinary liquids, but that below 39 degrees F. it strikes out a line of its own and begins to *expand* as it cools. The expansion at freezing, therefore, is merely a continuation of the expansion that began at 39 degrees F. In consistency, of course, when ice melts it contracts, and if the ice-water be heated it continues to contract up to 39 degrees F. It is not the thaw, accordingly, that bursts the water-pipes; the pipes may burst as the water cools, at any point below 39 degrees F. but if they have stood the expansion of freezing they are not likely to burst with the contraction of cold. Above 39 degrees F water expands with heat and contracts with cold, just like ordinary orthodox substances.

This expansion of water as it nears freezing-point, and at freezing-point, is of great climatic importance. If water, like most substances, continued to contract as it cooled, then the cooler, denser water would continually sink to the bottom, and ice would form on the bottom and not on the top of water. That might seem very good for a while; we might miss our skating, but it would leave the St. Lawrence and the Baltic open to ships all the year round, and it would produce a milder climate round coasts hitherto icebound. But it would seem good only for a while. The ice formed at the bottom of the sea and lakes and rivers would not melt Since water is a very bad conductor of heat, the sun would fail to reach it through the overlying water, and the surface water warmed by the sun would decline to sink and thaw it. It would remain all through the summer and autumn, and next winter a fresh layer of ice would be formed on top of it. This fresh layer, again, would persist through the succeeding summer and autumn, and would be covered by still another layer next winter

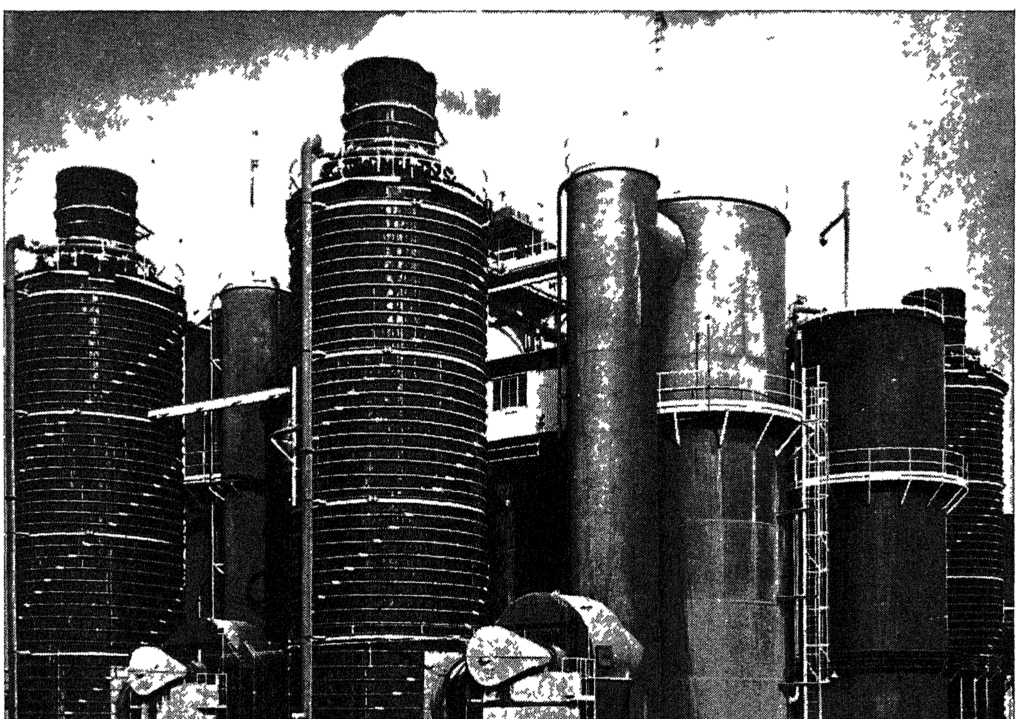
In time, at this rate, all the seas and lakes and rivers within the reach of frost would become solid ice, and all fishes and water-animals would be slain. And now the climate, at first rendered milder, would be rendered much more severe. It would be a case of slush in summer and ice in winter; and the continents of Europe and North America would become icefields populated chiefly by famine-stricken polar bears, and the centers of civilization would shift to the Amazon and the Nile.

Almost every known substance is to some extent soluble in water, and all natural water has solids in solution. In salt water the taste of the salts in solution gives evidence of their presence, but even fresh, tasteless water has a certain amount of solid substance in solution. The chief mineral substance dissolved in fresh water is carbonate

DRAWING MINERALS FROM THE SEA



"MINING" THE SEA FOR MAGNESIUM AND BROMINE AT THE DOW COMPANY'S TEXAS PLANT



Photos, Dow Chemical Company

THESE TOWERS ARE USED FOR EVAPORATING PURPOSES IN THE EXTRACTION OF MAGNESIUM

of lime. All water contains a certain small amount of carbon dioxide in solution, absorbed from the air; and water, again, containing carbon dioxide in solution is capable of dissolving carbonate of lime; and since carbonate of lime is almost everywhere present, so all water contains carbonate of lime in solution. Water containing much lime in solution, whether carbonate of lime or sulphate of lime, is known as *hard* water, and in such water some of the lime in solution is liable to be precipitated. So-called petrifying springs are produced in this way. The water issues with a large amount of lime in solution, and when the water evaporates the lime remains behind and forms an incrustation on any objects which are in it.

In this way, too, are formed the remarkable bodies known as stalactites and stalagmites. Water laden with lime drips from limestone rock through the roof of a cavern, and, as it evaporates, leaves a little lime behind. This deposit gradually increases until formations of lime, shaped like icicles, hang from the roof. These are known as stalactites. Again, where the drops fall on the floor of the cavern, they deposit a little carbonate of lime, and to this deposit, drop by drop, a little more lime is constantly added, until in time little conical rods of carbonate of lime stand up from the floor. These are known as stalagmites. Sometimes stalactites and stalagmites join and form pillars.

River-water holds in solution from two to fifty grains of saline matter per gallon — on an average, say, about twelve grains.

The percentage composition is as follows:

Calcium carbonate	42.90	Carbonates 57.70
Magnesium carbonate	14.80	
Silica	9.90	
Calcium sulphate	4.50	Sulphates 11.40
Sodium sulphate	4.20	
Potassium sulphate	2.70	
Sodium nitrate	3.50	
Sodium chloride	2.20	
Iron oxide and alumina	3.60	
Other salts	1.30	
Organic substances	10.40	
Total	100.00	

Sea-water, as is well known, and as its taste indicates, is much richer in salts than fresh water. A gallon of sea-water contains about 2450 grains of saline matter. Its chief saline constituent is not carbonate of lime, as in the case of fresh water, but sodium chloride or common salt — the salt we use at table. Out of the 2450 grains of saline matter contained in a gallon of sea-water, there are over 2000 of common salt.

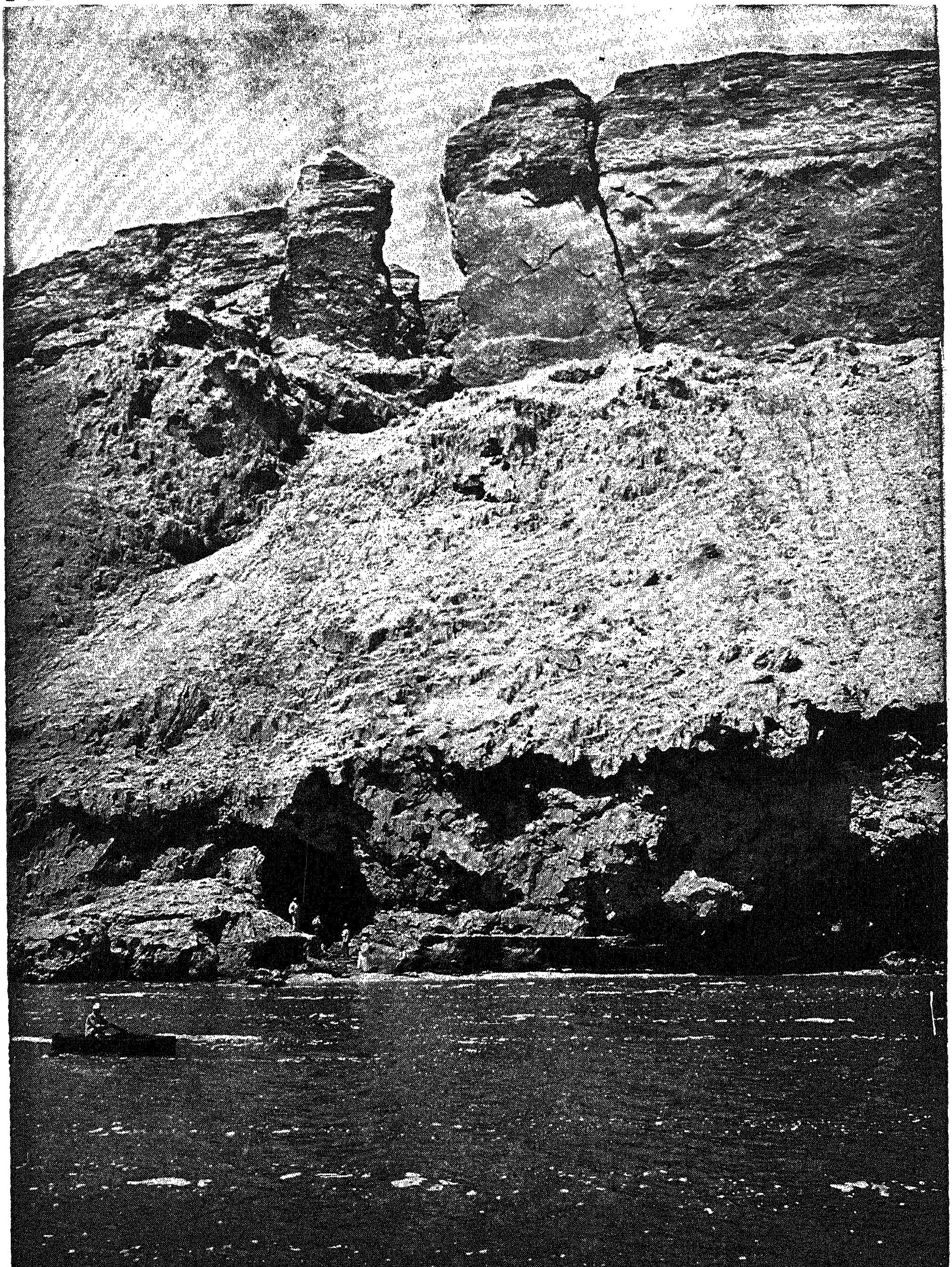
The constituents in parts per hundred are:

Sodium chloride	77.70	
Magnesium chloride	10.80	
Magnesium sulphate	4.70	Sulphates 10.80
Calcium sulphate	3.60	
Potassium sulphate	2.50	
Calcium and magnesium carbonate	0.30	
Magnesium bromide	0.20	
Other salts	0.20	
Total	100.00	

The solids, however, in solution vary in sea-water with the natural history of the water. The following interesting table, showing the salt contents of various seas, has been compiled by Bonney.

	English Channel	Mediterranean Sea	Black Sea	Caspian Sea (Baku)	Great Salt Lake (Utah)	Dead Sea
Chloride of sodium	2.7059	2.9424	1.4019	8.5267	11.8628	3.6372
Chloride of potassium	.0765	.0505	.0189	(trace)	.0862	.8379
Chloride of magnesium	.3666	.3219	.1304	.3039	1.4908	15.9774
Chloride of calcium						4.7197
Sulphate of magnesium	.2295	.2477	.1470	3.2493		
Sulphate of calcium	.1406	.1357	.0104	1.0742	.0858	.0889
Sulphate of sodium					.9321	
Sulphate of potassium					.5363	
Carbonate of calcium	.0033	.0114	.0364	.0554		
Carbonate of magnesium			.0208			
Bromide of magnesium	.0029	.0556	.0005			.8157
Water	96.4747	96.2348	98.2337	86.7905	85.0060	73.9232
	100	100	100	100	100	100

THE SALTY DEPTHS OF AN ANCIENT SEA-BED



A VIEW OF JEBEL USDUM, A MOUNTAIN OF ROCK SALT, WHICH EXTENDS FOR SIX MILES AT THE SOUTH END OF THE DEAD SEA, AND IS THE DEPOSIT OF AN ANCIENT OCEAN

It will be noticed that the salts in solution in the English Channel are not quite the same as the salts in solution in the Mediterranean, and samples collected by the *Challenger* showed variations between 3.301 and 3.737 in the percentage of salt in different parts of the sea. Besides these substances there are many other elements in solution in sea-water, such as iodine, fluorine, phosphorus, silicon, barium, lead, iron, copper, silver, cæsium and rubidium. Even a trace of gold is found, and more than one scheme has been proposed to recover it.

Since the salts in sea-water are derived from the land, it may seem strange that there is only a small quantity of silica and of carbonates; but the reason of this deficiency is that many marine animals and plants subtract the silica and carbonates from the sea-water in order to make themselves skeletons or shells. A single oyster requires all the lime in 27,000 to 76,000 times its weight of sea-water to make its shell. Spring-water contains more than ten times as much silica as sea-water; but at once the little unicellular plants called diatoms begin to use it to make their shell-like skeleton, and the store is quickly diminished.

As a rule, the water on the surface of the sea is saltier than the water in the depths, and the sea in regions where there is a large rainfall may have its salinity much reduced. The amount of ordinary salt (sodium chloride) and mineral matter in the sea seems inconsiderable when we state it as 3.3 to 3.7 per cent, but the following figures help one to realize how vast the amount really is: In every cubic mile of sea-water there are more than 117,000,000 tons of ordinary salt. If all the mineral matter in the sea were extracted and spread upon the dry land, it would form a layer more than 400 feet thick. If we could use the same mineral matter to extend the margin of the present continental areas out into the shallower seas, we could add about 20,000,000 square miles to the land surface of the globe; while if we were to heap up all the mineral matter on India, the Himalayas would be buried deep underneath. The common salt in the sea would itself form a continent having a bulk fourteen times that of the present European land above sea-level.

The result of all this mineral matter dissolved in the sea is to alter the thermal properties of sea-water as compared with the thermal properties of fresh water, as we have already described. The capacity for heat of sea-water is rather less, so that it is more easily warmed, and it conducts heat better. This very greatly increases the dynamical force of the sea. Sea-water is also more difficult to freeze than fresh: its freezing-point being about 28° F.

Most of the substances in solution in the sea have been added to it by the agency of streams and rivers; it is part of the débris of ancient continents. It has been added year after year, and century after century, and attempts have been made to estimate the age of the sea by calculating the time required to accumulate its salt.

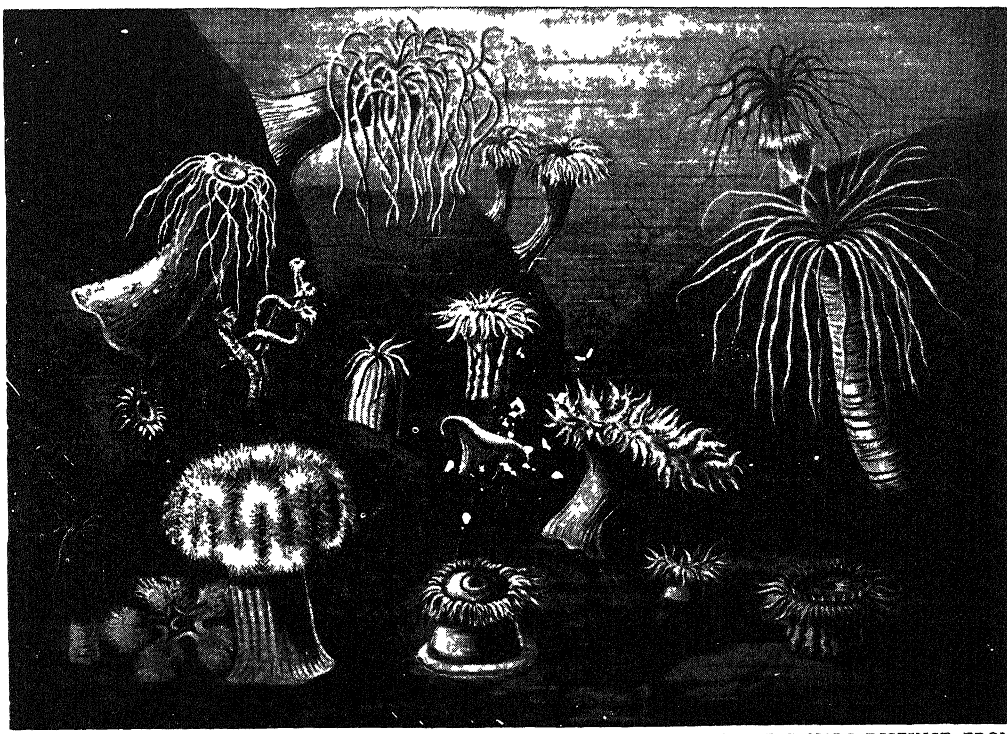
Its solvent power enables sea-water to act in a certain sense as a vital fluid. In the higher animals the blood functions in a fourfold way. It absorbs and distributes oxygen to the tissues; it takes up from the alimentary canal digested foods and transports them in solution to all parts of the body; it carries off waste products from the active cells; and lastly it equalizes in its circulation the body heat. In some low but showy forms of sea life, the polyps, for example, both soft and hard, fixed like sea-anemones and corals, and also in free swimmers, the whole body surface takes in oxygen dissolved in the sea-water and gives off carbon dioxide. In these animals, cœlenterates, the pharyngeal opening and digestive cavity allow free circulation of the sea-water, which takes up the digested food and carries it to the different tissues. The soluble waste products are swept away by this blood-substitute.

Water contains not only solids in solution but also gases. Whatever gases happen to be in contact with it enter into solution, the amount depending on the solubility of the gas, on its pressure, and on the temperature of the water. The greater the pressure, the greater the volume absorbed; the higher the temperature of the water, the less the volume absorbed. If gas is absorbed under a certain pressure, it will bubble out again when the pressure is reduced, as in "soda-water".

Natural waters are naturally in contact with the gases of the atmosphere, and therefore always have these gases in solution. At a temperature of 32° F. and at ordinary atmospheric pressure, 100 volumes of water will dissolve 2 volumes of nitrogen, 4 volumes of oxygen and 108 volumes of carbon dioxide, provided these gases are equally represented in the atmosphere, but since there is four times as much nitrogen as oxygen and only an infinitesimal amount of carbon dioxide, water contains in solution twice as much nitrogen as oxygen, and a very small quantity of carbon dioxide. The proportion of nitrogen in the water remains the same, however deep we go, but the proportion of oxygen diminishes, since oxygen is consumed in the processes of respiration by marine organisms.

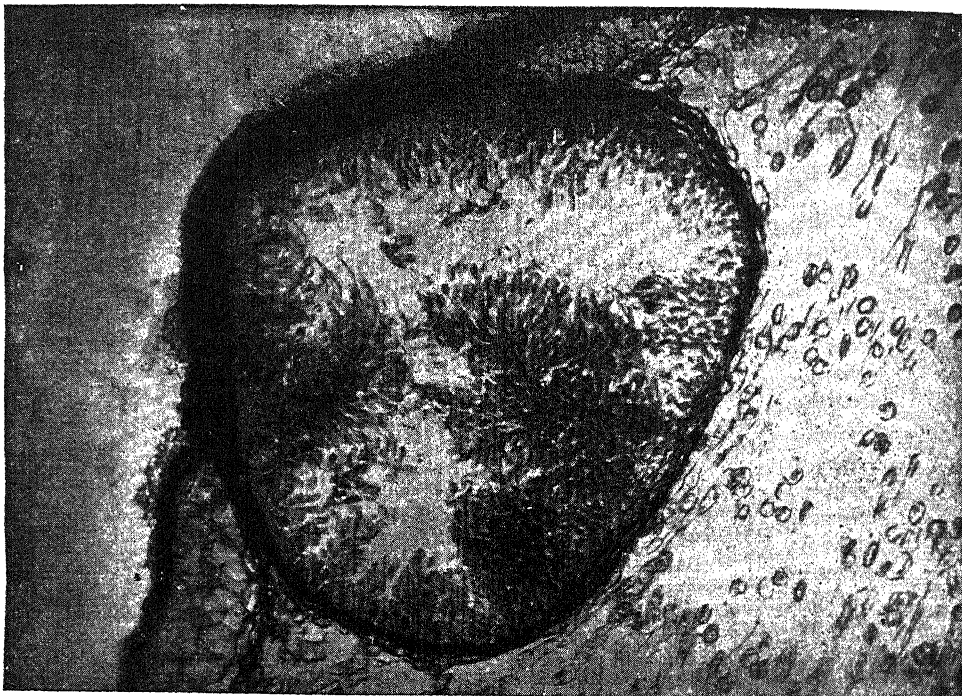
All bodies of water give and take atmospheric gases, as the pressure of these gases and as the temperature of the water rise and fall; and in the case of the sea this give and take performs a very useful office in maintaining the equilibrium of the carbon dioxide in the atmosphere.

Though carbon dioxide occurs in only small quantities in the air, it plays quite an important part in the regulation of the temperature of the earth, and in the due performance of the respiratory functions of animals and of the digestive functions of plants. A little deficiency or excess would seriously affect all these; and it is produced in such large quantities by animals and volcanoes and coal-fires, and is consumed in such large quantities by plants and rocks, that considerable variation in its total volume might very well take place.

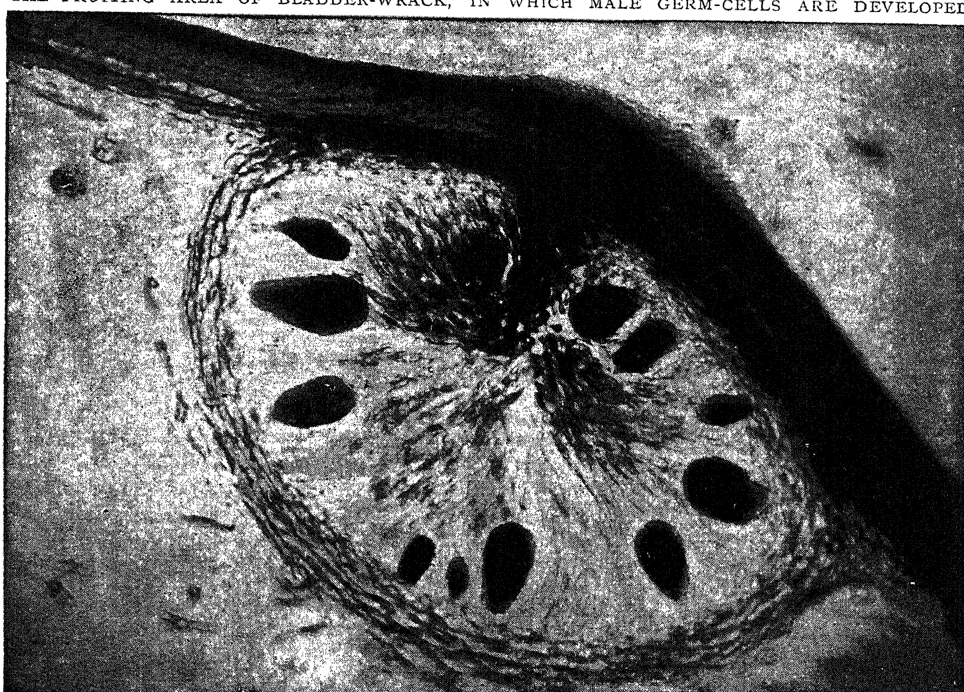


CŒLENTERATES EXEMPLIFIED BY SEA-ANEMONES, WHICH LACK ALIMENTARY CANALS DISTINCT FROM THE GENERAL CAVITY OF THEIR BODIES

Such variations are, however, automatically checked by the sea; for as the pressure of the carbon dioxide in the air rises, more enters into solution in the sea; and as it falls, some of it in solution in the sea returns to the air. How effective this regulation is the following will show: at present there are 3 volumes of carbon dioxide in 10,000 of air. In order to increase the proportion to 4 in 10,000 it would be necessary to more than double the amount originally present, for the sea would absorb much the greater part added.



THE FRUITING AREA OF BLADDER-WRACK, IN WHICH MALE GERM-CELLS ARE DEVELOPED



CONCEPTACLE OF BLADDER-WRACK, IN WHICH FEMALE GERM-CELLS ARE DEVELOPED

In the upper of these highly magnified photographs the spermatozoids can be seen in their receptacle, and in the lower are seen the large, dark-colored oogonia in which are produced the eggs which are fertilized by the spermatozoids. Photos by Mr. J. J. Ward.

STUDIES IN HEREDITY

How Darwin and Galton Made a New Scientific Orthodoxy Which Has Already Been Superseded

THE FAILURE OF RESEARCH BY ARITHMETIC

IF we recall our study of reproduction, we shall realize that heredity offers no problem in the simplest possible instances. The bacillus or the amœba divides into two, and as each is half the parent, its resemblance to the parent is in the nature of the case. As regards the amœba, which has a nucleus, we saw that the contents of the nucleus are simply subdivided between the "offspring", to use a word which is evidently not yet applicable to the process of reproduction in such humble forms of life. In the case of the yeast plant we can speak of "offspring", for the young cell does spring off, so to speak, from the parent; but it is palpably part of the parent, and again the resemblance between the generations offers no problem to the student of heredity. Further, in such cases as these, which are drawn both from the animal and from the vegetable kingdoms of the living world, the new individuals are born adult. They have no youth, no immaturity, no period of development. So much the less is there any problem to study. We do not have to compare mature parents with immature offspring; we do not have to ask how the development of offspring, from immaturity up to a condition in which they resemble their parents, is made dependent upon the composition of "germ-cells" in which no trace of the future organs and limbs and features can be observed by the most powerful microscope.

Nevertheless, let us duly note these cases, and their simplicity; for the great initial discovery, upon which modern genetics is based, was the tracing of the hereditary process, in even the very highest forms of life, to just this same simple, continuous cell division as the amœba illustrates. That, in a word, is what the theory of the germ-plasm and the "continuity of the germ-plasm" means; and when we talk of germ-cells and study their origin from cells in the germinal tissue, though they be the germ-cells of an oak or of human beings, we are studying a series of processes of cell division which set free from the parent individual cells destined to carry forward the life of the race though all this is hidden from our eyes by the extraordinary development of the individual body from and around these germ-cells. And thus, if the resemblance between daughter amœba and the parent amœba is really no problem — for they are the mother, subdivided — so also the resemblance between successive generations of other species is seen to be inevitable, for the body of the parent is sprung from a "continuous germ-plasm", of which a further portion, reserved for the purpose years later, gives rise to the body of the offspring. Naturally, then, parent and offspring resemble each other in so many particulars, the bodies of both having really been developed from almost the same material.

If this be a sound conception of the process of heredity, if the sequence of the generations be not from parental body to germ of offspring, but from germ to germ, with the parental body as a bridge or a protective host, performing a temporary service for the "immortal germ-plasm", then we may begin to doubt whether the accidental happenings to that parental body can affect the germ-race within it, or

the features of future bodies which may be developed therefrom. Thus, if the parental body "acquires" the character of losing an arm, we need not expect that this accident will affect the germ-plasm, and the number of arms of future offspring, any more than if the parent had lost not his arm but merely the sleeve of his coat. In either case the loss is irrelevant to the history of the germ-plasm which the arms of the individual body (and the sleeves covering them, for the matter of that) exist primarily in order to protect. Very different would the case be if Darwin's theory of pangenesis were true, and the germ-cells were made by contributions representative of every part of the individual parental body; but that, as we have seen, is not the case.

This assertion, that the modifications of the parental body, which is merely the host or trustee of the germ-plasm, do not affect it, and are therefore not transmissible to offspring, was first laid down by the late Sir Francis Galton. This theory is generally credited to Weismann, and undoubtedly Weismann has done the greater part of the work associated with it, as we shall see, but the first denial of the commonly accepted view — which played a large part, we remember, in the evolutionary system of Lamarck — was made by Galton. Here is his own statement, made at a later date, of the view in question: "As a general rule, with scarcely any exception that cannot be ascribed to other influences, such as bad nutrition or transmitted microbes, the injuries or habits of the parents are found to have no effect on the natural form or faculties of the child."

The position of the study of heredity when Galton took up the subject

The reader should note the words "bad nutrition or transmitted microbes", for they indicate two great realms of causation that have been generally forgotten by students and advocates of the Galton-Weismann theory. But we shall see this more clearly when we come to study Weismann's own individual contributions to the subject.

Those contributions depend upon a particular line of research, the microscopic study of germ-cells, which made a new chapter in the study of heredity, and is adding to that chapter today. But first we must deal with Galton's work, his characteristic method, and the results to which it has led. He founded a definite school, which has attained great prominence in London, though not elsewhere, and the members of which are now contributing copiously to the literature of the subject.

When Galton came to the study of heredity, half a century ago, he found it a chaos. A sharp distinction was made between heredity in animals and heredity in man, most authors admitting the former but denying the latter. The time was ripe for a fresh start. The "Origin of Species" had just been published, and the importance of the study of heredity had risen accordingly, and it had become of even sensational interest, not least as regards man, whom the Darwinian theory classed definitely with the lower animals. As Galton says, "The subject of human heredity had never been squarely faced, and opinions were lax and contradictory. It seems hardly credible now that even the word heredity was then considered fanciful and unusual. I was chaffed by a cultured friend for adopting it from the French."

The incalculable service of Galton's study in calling attention to the question

Galton had himself inherited a strong statistical bent. He liked to reduce everything to numbers, and then study and compare them. His study of heredity was statistical in conception and in detail, and the conclusions which he reached are statistical laws, capable of mathematical expression. His service to the study of heredity, by his interest in it and the discussion his work aroused, is incalculable, but we must pay no reverence to any statement or theory which proves to be erroneous, and unfortunately time has played sad pranks with the greater part of Galton's work, chiefly owing to that of his contemporary Mendel, who was born in the same year, 1822, and to whom he paid generous tribute.

We have already seen that it is all-important, in our study of heredity, to distinguish between true variations, which have their origin in the germ, and the mere results of the interaction between the individual and the environment. Those results may alter the individual in various ways, including the chance of modified nutrition, and of infection with microbes, so that the individual's relation to his offspring is different from what it would otherwise have been. But while these particular differences wrought in the individual are important from the point of view of his offspring, neither they nor any other "acquired characters" or "functional modifications" have any bearing whatsoever upon his actual relation to his ancestors. In studying, then, the measure of likeness and unlikeness between any individual and his or its ancestors, we absolutely must exclude the influence of environment upon the individual. That may be somewhat difficult, but if it is not done we cannot come to a definite decision as to what heredity is actually doing in the case in question.

Galton's statistical examination of variations to illustrate Darwin's ideas

Now Galton was Darwin's cousin, and his interest in heredity was chiefly aroused by the book in which Darwin had declared the natural selection of small random variations between members of a species to be the efficient cause of organic evolution, and of the adaptation of living species each to its niche in the world. Hence the study, as exact as possible, of these alleged variations became immensely important, and the method of Galton was to attack the problem statistically. Let us have large numbers of individuals measured, in various respects, have the measurements compared, and then we shall be able to state a "law" of the distribution of variations. And thereafter we shall be able to see how natural selection of the favored instances among these variations would affect the "origin of species". Such were the lines of reasoning of this investigator, one of the last of the great English non-professional men of science.

The Galtonian mistake of including variations that were not transmissible

But if the mere results of external accident, as regards a thousand factors, are not transmitted by heredity, we shall make no useful contribution to anything unless we are quite certain that the random variations we study and measure are genuine germinal variations, inherent and therefore transmissible, instead of being superposed from without, and therefore shed with the shedding of the individual as the race goes on. And that is where all this enormous mass of work has broken down in recent years. The workers have done everything else, but they have left undone what was really the first task of all, which was to prove that the differences they observed were inheritable. We call them "variations", which we have agreed to define as germinal, not "acquired", but if we find that they are not germinal we shall want a new name for them. At first, when their real character was suspected, biologists called them "fluctuating variations", and now they are very generally spoken of simply as "fluctuations".

The danger of resting on names and numbers and neglecting the facts

This is a most instructive chapter in the history of science, for it teaches the old lesson — that we must keep close to the facts unless we are content to go wrong. Names and numbers will not do, if they do not agree with things. The pioneers in this case are not to be blamed, but their smaller followers, as in a thousand other instances. Darwin was a first-hand observer, and made many experiments. If this had been a task for one man, or for ten ordinary men, he would have done it. As it was, Darwin could only collect materials for the future study of variation. It is in the nature of this kind of work to require time, as astronomy does — you cannot observe characteristics of great grandchildren, and compare them with their ancestors, until life has reached them. Galton, also, made many valuable first-hand observations, such as those already quoted, which disposed of Darwin's theory of "pangenesis".

How Galton's followers continued to stereotype his errors of classification

But the followers of these great men went on other lines. They counted and calculated and assumed. To them a variation was a variation, and its transmissibility could be taken for granted. Their great concern was to discover how these variations were distributed, and thence to reckon what effect various degrees of selection would have upon the race; not troubling to remember that the selection of not inheritable characteristics would have *no* influence on the race. Their calculations resulted in a very definite conclusion, which entirely agreed with the assumption of Darwin, that variations occur in all directions. These measurers of life, or "biometricians", as they are now called, showed that offspring vary in all directions from the type of the parents.

"Variation" — only we must beware of the word — was essentially an affair of the law of chance. Curves could be plotted, showing the distribution of variation among the individuals of a given generation, and it could be shown that this obeyed, as a whole, a law familiar to mathematicians.

The futility of laws of average that prove nothing at all

If we examine all the shots upon a target after very many have been fired, we find that they have a "probable error" that can be measured. Most will be near the bull's-eye, and there will be a gradual thinning as we leave it, until we encounter only a stray shot here and there; and we can readily predict, in a simple formula, the proportion of the total number of shots that will probably show any particular measure of error from the straight path to the bull's eye.

Now it is a fact, statistically proved by these students, that if we examine a very large number of peas or people, leaves, hairs or almost what you will, this law is illustrated by them. There is a sort of average or mean for them, and the further we depart from that, on either side, the fewer will be the number of individuals represented.

Laboratories of life into which no living creature was taken for observation

All this, when studied in detail, becomes very interesting, and is found to be perfectly true. It is exactly what is required for the theory of the origin of species by the natural selection of minute variations which favor survival. Distinguished mathematicians have constructed elaborate and consistent theories of the details of organic evolution, supposed to occur in this fashion, and Galton himself was unfortunately misled, making no experiments in the later decades of his life, and devoting large sums of money to the establishment of "laboratories" for the study of life into which no living creature is ever taken for observation.

The rediscovery of the work done by Mendel many years before had led to many indirect as well as direct consequences. One was a sudden revival of interest in actual breeding experiments, which had been astonishingly neglected while men argued and wrangled and reckoned over theories contained in the "Origin of Species". Only actual breeding experiments could really meet the needs of biology. Darwin did the best he could, but for the most part he was compelled to rely upon the statements of breeders of cattle, gardeners, fanciers and others, whose motive was not scientific, and whose training was no more so. Of course, this could not be expected to suffice.

The statistics of variation proved by experiment to be beside the mark

At whatever expense, at whatever cost of time and labor, biologists were plainly required to make breeding experiments, to which there will never be any end, and thus "to put the question to Nature", as Bacon said, definitely and rigorously, so that nature might return definite and rigorous answers. Recent years have witnessed the practice of such experiments, by men of science with purely scientific ends, on a scale which is certainly not one-millionth of what we need, yet which far exceeds anything of the kind ever attempted by man. Since then "everything is different".

The most remarkable and important discovery of all, negative, indeed, yet more important even than the positive results attained long before by Mendel, is that these "fluctuating variations" or "fluctuations", in all directions, with a regular distribution, from the mean or type of the species, *are not inherited.* They are not germinal, but nutritive — dependent upon the relations between the individual body and the chances of the environment, and thus occurring, on the average, according to the mathematical laws of chance. Not being germinal, these variations, so called, are not inheritable, for inheritance, as we have seen, is really from germs to germs, under cover, as it were, of the individual bodies which contain them. The "variations" so minutely studied were only differences between those bodies, and are therefore seen to have nothing to do with the process of heredity, and therefore *nothing to do with organic evolution.*

Dissolution of the theories of heredity inherited from Darwin through Galton

The writer has failed inexcusably if he has not made plain to the reader the fundamental and overwhelming importance of this conclusion. At one touch of first-hand knowledge, rightly obtained for the special purpose in question, the whole structure of the orthodox theory of evolution, built upon numbers and formulæ and curves on paper, is dissolved.

Professor Bateson's course of lectures on "The Study of Genetics" must have given any amateur student of these subjects a series of surprises. Such amateurs, for the most part, are largely interested in the subject from its bearings on religious belief. They have read the works of Haeckel and Grant Allen, Mr. Edward Clodd and Mr. Joseph McCabe, as well as their volumes of Darwin and Huxley; and they have come to the inevitable conclusion that, as against Genesis, Darwinism must prevail. Genesis for them is orthodoxy, the conventional view in which they were brought up; and Darwinism is the heterodoxy, the daring novelty which the champions of new truth must accept. Let us remind ourselves that Darwinism is only a particular theory to account for organic evolution, which is itself now quite generally accepted, and then let us picture the bewilderment of any ordinary well-informed reader of these subjects who heard Professor Bateson's frequent references to "the orthodox theory", "the conventional interpretation", "the views which we were brought up to believe". These references, inevitable and natural, considering the nature of his subject, and before long quite unremarkable to the ears of those who listened intelligently, were not to Genesis, but Darwinism.

Not even the youngest of us were all brought up to believe in Darwinism as the conventional and respectable view of orthodox people; but if we were, it is time for us to make a fresh start. The assiduous and devoted mathematical study of variation, initiated by Galton, and hailed by certain of his successors as conclusive in its proof of the efficiency of natural selection of minute variations in the formation of new species, avails nothing at all in presence of the demonstration by nature, when the question is put to her, that these variations are not inherited.

How the beginning of the study was mistaken for its completion

It is the end of a strange chapter in the history of science, but apparently many years will pass before it is a matter of general knowledge how far biology has gone, in our own century, beyond the furthest point reached even by Darwin.

Here are words written by Professor Bateson in 1909, the Jubilee year of Darwin's masterpiece:

"The 'Origin' was published in 1859. During the following decade, while the new views were on trial, the experimental breeders continued their work, but before 1870 the field was practically abandoned. In all that concerns the problem of species, the next thirty years are marked by the apathy characteristic of an age of faith. Evolution became the exercising ground of essayists. The number, indeed, of naturalists increased tenfold, but their activities were directed elsewhere. Darwin's achievement so far exceeded anything that

was thought possible before, that what should have been hailed as a long-expected beginning was taken for the completed work. I well remember receiving from one of the most earnest of my seniors the friendly warning that it was waste of time to study variation, for Darwin had swept the field."

And Darwin had never even heard of Mendel! One gasps at such blind advice.

So much for the most important fact which research has brought to light since the mathematical study of variation was initiated. Fluctuations are not inherited; and all the criticism of the theory of natural selection, which we have put forward in previous chapters, based partly on the writings of Bergson and partly on other grounds, may be regarded as superfluous from the practical standpoint for the all-sufficient reason that, with the disproof of the inheritance of fluctuations, the whole theory of organic evolution by means of natural selection falls to the ground.

The absence of the absent accounted for, but not the presence of the present

The theory will account for the absence of the absent, because they were not able to survive in the struggle for existence, and that is a most important contribution to our knowledge, but it tells us nothing as to the presence of the present. We may refrain from observing that the origin of variations has to be accounted for, we may recognize the fact of adaptation in fullest degree, we may grant that variations around the type of any species will some of them tend to favor survival, and will therefore be selected for life and parenthood, but when, at this point, we find that those variations, having been selected, are not inherited, the bottom drops out of the chariot of our fancy, and when we pick ourselves up it is not for further adventures in that vehicle.

But if our history of this chapter in biology is to be at all complete, we cannot leave it without reference to two famous laws, or generalizations, which were framed by Galton, and which are still very frequently referred to in semi-popular writings and by the biometricians, though they no longer interest biologists very much.

The arithmetical basis of Galton's law of ancestral inheritance

The first "Galton's law" is also often called the "law of ancestral inheritance". Its author made a study of a very large number of statistical data as to health, eye-color, stature, etc., in several generations of some hundred and fifty distinct families. Then he made a similar statistical analysis of the colors of a large pedigree stock of Basset hounds. And he found that, both for the human beings and for the dogs, the following law could be affirmed: "The two parents between them contribute on the average one-half of each inherited faculty (or character), each of them contributing one-quarter of it. The four grandparents contribute between them one-quarter, or each of them one-sixteenth, and so on, the sum of the series, $\frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \frac{1}{16}$, etc., being equal to one, as it should be. It is a mathematical property of this infinite series that each term is equal to the sum of all those that follow."

The failure of the law when tested by the study of actual cases

In his book, "Variation in Animals and Plants", published in 1903, Dr. H. M. Vernon, a well-known authority, expressed the opinion that Galton's law "renders the whole theory of heredity simple, straightforward and luminous". How times have changed! Dr. Vernon did not then know the fatal objection which experiment was to bring against any theory of heredity that depended in any degree upon the study of characters that are *not inherited*. The first-hand study of the details of breeding, *with analysis of each individual case*, instead of statistical jumbling of all cases in one wild confusion — which looks orderly because it can be numbered precisely — led in half a dozen years to the verdict of Bateson that, "no one familiar with breeding, or even with literature of breeding, could possibly accept that theory as a literal or adequate presentation of the facts." And this was the "law" which a few years earlier had been said to "render the whole theory of heredity simple, straightforward and luminous"!

Little better is the fate which has overtaken the second of Galton's chief generalizations, the "law of regression to mediocrity". This is another statistical assertion, based essentially upon the putting together, which means the confusion, of large numbers of individual *data*, as opposed to the method of analysis of each *datum* separately.

The lengthy literature of Galton's law of regression to mediocrity

Not so many years ago, practically everyone accepted both of these laws of Galton, and based arguments upon them in relation both to natural selection and to the theory of eugenics. But the "law of ancestral inheritance" has had to be abandoned in face of the evidence, and later it has become clear that the law of "regression to mediocrity" must go also. This law asserts that there is a constant tendency for offspring of parents who have varied from the type, either on one side or the other, to return to it. This return is called regression, a very good name for it, and it constantly tends to keep the species along the line of the great majority of its representatives — that is to say, along the line of mediocrity. Thus the offspring of exceptionally tall plants, shall we say, will be taller than mediocrity, but not so tall as their parents; and the offspring of exceptionally short ones will be shorter than mediocrity, but not so short as their parents. Similarly, the children of genius will be clever, but nearer mediocrity than their parents; the children of criminals will be wayward, but less so than their parents.

This "law" can no longer be accepted. The same radical confusion between the truly germinal and the results of environment pervades it. It does not survive the test of experiment. Further — and this is the most unexpected argument — we begin to see that this law, which sounds so scientific and exact, is really quite mystical and unreal. We learn to look at it so from the very first day on which we start our study of germ-cells. We learn that the characteristics of the individual depend on the composition, contents and structure of the germ-cells that make it.

The failure of the law of regression when tested by experiments

According to the law of "regression towards mediocrity" one would have to examine the ancestors of any individual in order to learn its future. If the individual came of parents, say, very tall, whose tallness was the mediocrity of their stock, then the offspring would be as tall; but if the parental tallness were exceptional, then the offspring would "regress" and not be so tall as their parents. In so far as illustrations can be cited for such a theory, they depend upon exceptional nutritive or environmental conditions — *e g*, bad nurture stunted the parents, and the offspring are taller. This has nothing to do with heredity, though it looks like an illustration of "regression towards mediocrity". The hereditary or natural characteristics of the individual depend not on the features of the bodies of its parents and grandparents and so forth, as is assumed in the "laws" of Galton, but upon the facts of the actual germ-cells from which the individual is developed In a word, we have put these magnificent statistical generalizations under the microscope, and we find that there is nothing in them; the microscopic study of germ-cells has shown us their unreality, once and for all.

Here are the bold and unequivocal words used by Professor Bateson in 1909, much criticized at the time, but now hardly noteworthy — so amazingly rapid has been the development of our knowledge. Dealing with the state of things prior to the rediscovery of Mendel — "with the year 1900 a new era begins" — in the last year of the nineteenth century, he says:

"Of the so-called investigations of heredity pursued by extensions of Galton's non-analytical method, and promoted by Professor Pearson and the English Biometrical School, it is now scarcely necessary to speak. That such work may ultimately contribute to the development of statistical theory cannot be denied, but as applied to the problems of heredity the effort has resulted only in the concealment of that order which it was ostensibly undertaken to reveal.

The hopelessness of methods which dispense with great essentials

"A preliminary acquaintance with the natural history of heredity and variation was sufficient to throw doubt on the foundations of these elaborate researches. To those who hereafter may study this episode in the history of biological science it will appear inexplicable that work so unsound in construction should have been respectfully received by the scientific world. With the discovery of segregation — the peculiar behavior of germ-cells, upon which Mendel's law is based, as we shall see — it became obvious that methods dispensing with individual analysis of the material are useless. The only alternatives open to the inventors of those methods were either to abandon their delusion or to deny the truth of Mendelian facts. In choosing the latter course they have certainly succeeded in delaying recognition of the value of Mendelism, but with the lapse of time the number of persons who have themselves witnessed the phenomena has increased so much that these denials have lost their dangerous character and may be regarded as merely formal."

Professor Bateson's strong words justified by subsequent reports of biometricians

Let us praise great men, and honor Galton for having admitted the fact of Mendelian segregation in the autobiographical volume which he published in 1908, three years before his death. But meanwhile his followers have committed themselves irrevocably to methods which their master would now be the first to recognize as obsolete and inadequate; and if anything were needed to justify the very strong words which Professor Bateson wrote, in 1909, regarding the uselessness of methods which dispense with individual analysis of the material, that justification is to be found in the subsequent reports of the biometricians on the influence of parental alcoholism upon the offspring, when they omitted to ascertain, in a single case, whether the parental alcoholism had occurred before or after the conception and birth of the offspring; and on the alleged inheritance of tuberculosis, where they omitted to take into account the fact that tuberculosis is an infectious disease.

Going back to nature the only sound method of biological study

No; the study of living things cannot be conducted by the manipulation of figures and formulæ at a desk In order to study them one must live with them and watch the details of their lives. We must go back to nature. That is exactly what biology, all over the world, has done since the dawn of the present century, after very nearly a generation of words and numerals The nineteenth century was not wholly without men who would not be drawn away from the only method by which natural science has ever taken a single sure step. Darwin, of course, was the greatest of them. He did not sweep the field, but at least he surveyed it.

How the veteran Weismann restored living contact with living things

Mendel was another, but by the accident of the remoteness of Brünn from London or Paris, or even Berlin, his work of 1865 dates, in the development of biology, from 1900, the year of its recognition Weismann was another, though the work of Mendel, whom Weismann survived by a quarter of a century, is leaving Weismann's behind. But we should not be where we are without the veteran of Freiburg, rightly named August; and his study of germ-cells will restore us to that living contact with living things without which the science of life must ever languish and die. Nay, more; for Weismann has served science no less by interpretation than observation; and, like Darwin and Galton — though all three may now be largely superseded — he put forward clear and arguable ideas, which have stimulated thought and inquiry in every branch of science to new and vital efforts.

GROWTH OF ROOT AND STEM

The Different Forms and Adaptations of Roots
and of Stems — Climbing, Twining and Woody

THE THRUST OF LIFE TOWARDS FOOD

We have now discussed the structure of the simplest form of plant that one can imagine — namely, a seedling. We have further noticed how nutrition is carried on in plant life generally, and the source in nature from which the plant derives its different nutritive materials. And, again, we have seen that this search for food on the part of the plant is not limited to providing for present needs alone, but that it includes preparations for accumulating a sufficient store of food for future necessities. These necessities are of two kinds. In the first place, food is stored up so that the embryo in the seed may have something to fall back upon before it can provide for its own requirements; and, in the second place, food is stored up to enable plants which live for more than one season to utilize a reserve supply during the months of physiological inactivity.

In a previous chapter we observed in some detail exactly how the seedling made its appearance, and we are now, therefore, in a position to devote our attention to what we may term the *physiology* of plant life; in other words, how plants carry out the different vital functions upon which their existence depends. These functions are very much the same in both plants and animals; it is only the means whereby they are effected which differ very markedly. The two primary functions of plant life — apart altogether from reproduction — are the questions of feeding and breathing; and it is to the successful carrying out of these forms of cell activity that most of the structures in the plant are devoted.

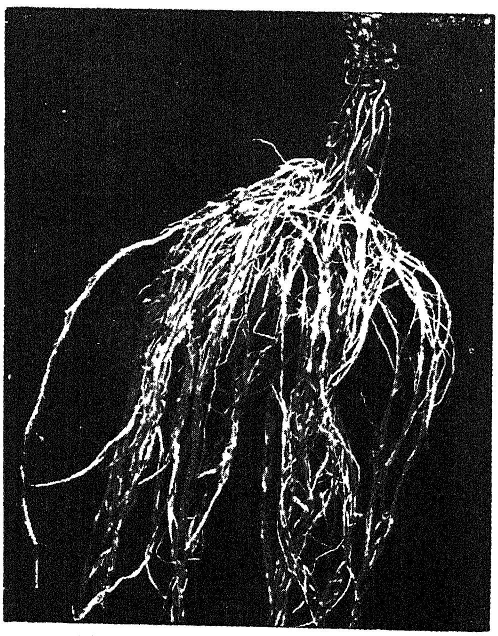
The question, therefore, which now arises for our study is — how do plants feed and breathe? This resolves itself into an examination of the structures known as "roots" and "stems" and "leaves," and used in feeding and breathing.

The reader will recollect that these three elements are precisely those which first of all made their appearance in the developed seedling. The radicle emerged from between the cotyledons, and grew downwards, in evident anticipation of the structure and function of roots. The plumule grew upwards towards the surface of the soil, in evident anticipation of the structure of the stem and all its parts. And in some forms of seedlings the cotyledons themselves took on the form and appearance of green leaves; so that root, stem and leaves may be considered as the primary formation of the parts of a plant. These parts, as a matter of fact, are commonly present in all flowering plants.

The primary root of any plant is the ultimate growth of the radicle from the embryo, which, as we have seen, takes a downward course in the soil, growing by means of the cells at its extremity. This growth, however, does not extend indefinitely in this direction or in this manner, because after such a primary root has extended for several inches we may observe that it begins to give off branches, having a somewhat similar appearance and structure to itself, only upon a smaller scale. Moreover, these branches do not grow downwards, but, coming off at right angles from the primary root, they extend laterally, growing, as does the former, by means of the cells at their extremities.

These lateral roots are termed "secondary". In turn, as growth increases, they give off further branches, growing out obliquely from themselves, and these may be termed "tertiary". So this subdivision of roots goes on until we may get a very complicated arrangement, the whole being termed the "root system" of the plant.

The oldest among the primary roots are those which arise nearest to the original position of the cotyledons, and the youngest are those nearest the tip of the primary root, these positions enabling one to determine their relative age. Moreover, they

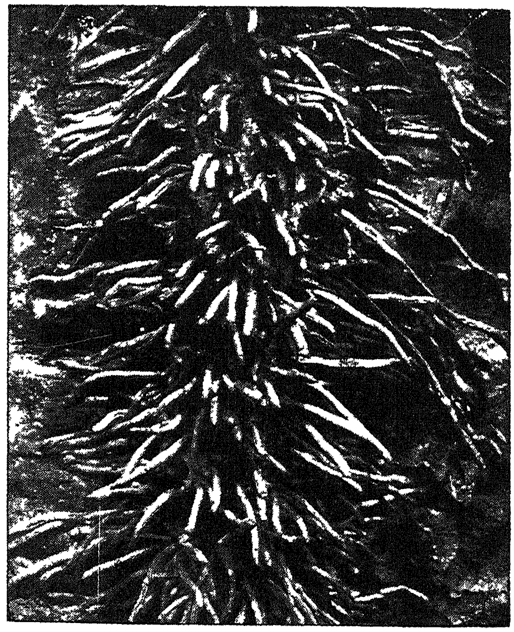


THE FIBROUS ROOTS OF GROUNDSEL

take their origin from within the primary root itself, and are connected with its interior structure.

When the primary root continues to grow prominently, overshadowing in size and strength all secondary roots, we get what is termed a "tap" root, such, for example, as is found in the carrot, and many trees. When the root assumes a more or less irregular, swollen appearance, it is termed "tuberous", and is usually used as a storehouse for food. On the other hand, in many plants the primary root becomes quite overshadowed by the subsequent growth of the secondary and other branches; and when this is the case, the plant, when pulled out of the ground, shows a complicated bundle of roots, all of which are very much the same size and shape, and are spoken of as "fibrous" roots. The common groundsel is an example.

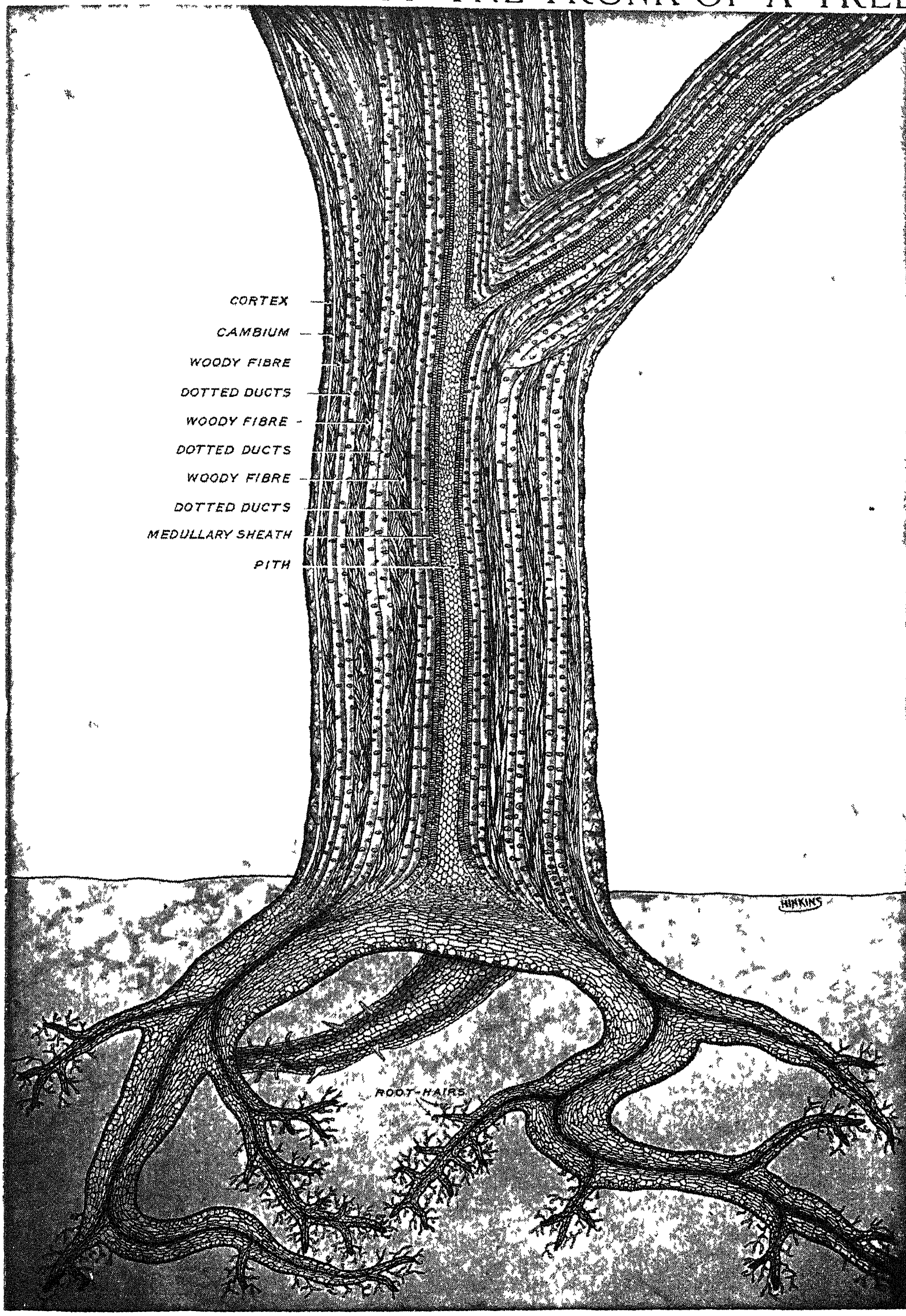
In some other cases the primary root is only a temporary structure, and is succeeded not by branches arising from itself, but by new roots coming from the stem of the plant. Such a case is observed in the onion. Other roots, again, spring from the different parts of the stem of the plant, and even sometimes from leaves, and these are termed "adventitious".



THE ADVENTITIOUS ROOTS OF IVY

Cases of this kind are found among most of the farm plants—for example, in wheat As we have seen, the embryo of the wheat plant has only three roots, and these are merely of temporary service, being succeeded, by the time the leaves are appearing, by a number of adventitious roots, which take their origin from the lower part of the stem. These adventitious roots, too, are found arising from underground stems, as is excellently seen in the mint plant. The potato is another example of the same thing. They also arise from runners, as is well exemplified in the strawberry plant.

THE STRUCTURE OF THE TRUNK OF A TREE



This picture-diagram of a section through a three-year-old tree shows the various layers that go to make up its stem and insure the stability, growth and nourishment of the tree. The arrows indicate the course of nourishment from leaves to roots and roots to leaves.

All these adventitious roots are apt to occur at the joints in stems, in the same position at which leaves arise, and their appearance is commonly decided upon by the environment; that is to say, so long as the stem is in the air they do not show themselves, but should it come in contact with the soil with sufficient moisture, then they quickly grow. They may, however, arise apart altogether from such circumstances. Nothing is more curious than to observe that these adventitious roots can be made to grow from almost any part of certain plants; and so widely is this recognized that, as a matter of fact, the methods of propagation of many species are determined by this principle. All that is necessary is to take a number of cuttings and place them in the ground, when, climatic and other conditions being favorable, a number of young adventitious roots will make their appearance, and secure food to keep the cutting alive, and ultimately produce a new individual. This is the common way of propagating gooseberries, currants, roses, etc Such adventitious roots are nearly always of the fibrous nature. Rarely do we find them assuming the tuberous form that is seen in the dahlia plant.

THE LATERAL GROWTH OF THE ROOTS OF A BEECH-TREE
Owing to the hilly situation on which this tree stands, the soil round the roots has fallen away, leaving the root structure bare.

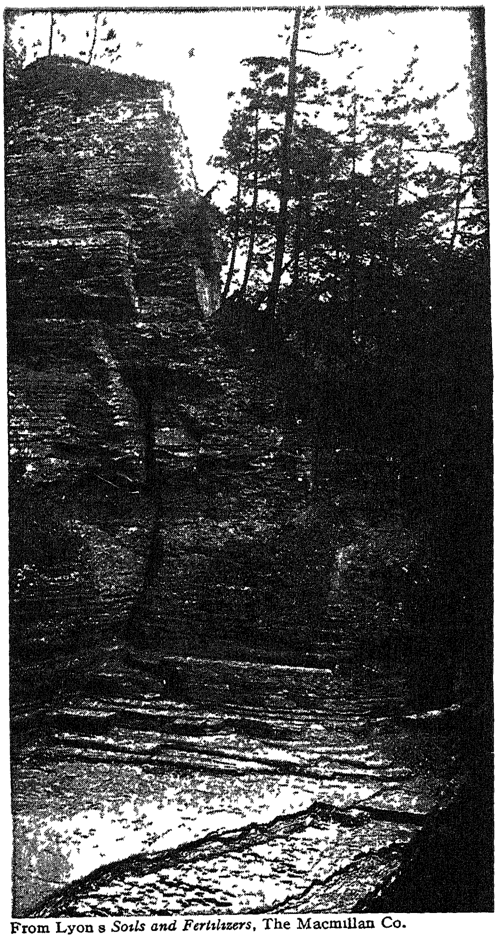
Having been produced in the way above described, the roots of plants and trees spread themselves out in various directions in their search for food; and an example of an uprooted tree will soon show the observer that the growth directly downwards does not extend for any very great depth. As a matter of fact, but few trees send their roots more than a few feet down into the earth.

On the other hand, however, there may be very great extension in the horizontal direction. This is obviously because at a certain distance in the soil the root comes to a region where there is neither moisture nor suitable food. Indeed, the deepest parts of such roots are more for purposes of fixation than nutrition. The latter function is carried on chiefly by means of the fine, small rootlets which arise all over the secondary and other roots, and which are broken off when a plant is pulled out of the ground, their number, on this account, not being readily appreciated.

The condition of the soil will obviously have a considerable effect upon the character of the growth of the root system, apart altogether from the kind of plant concerned. The stiffer the soil, the more compact will be the root system; and, on the other hand, in a very loose and sandy ground the roots will spread far and wide. Adequate fertilizing, too, produces an extra supply of roots, so long as this is not carried to excess.

The different kinds of root, associated with different species of plants, call for close attention on the part of the grower, in so much as the method of tilling the ground, or preparing it, will have to vary considerably to meet the kind of root system in each case. Roots which go to considerable depth will obviously require that the soil should be worked in proportion, whereas roots which are mainly of the surface type can be dealt with on a soil of a much thinner character.

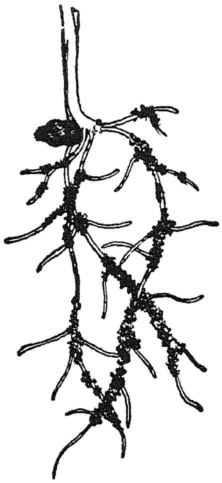
Perhaps the most important structures of all in connection with roots are those which are termed "root hairs". These are not found at the extreme of the growing point, but at a short space behind it. They are always found in this position, and they occur not only upon the primary roots but upon the secondary and other roots, as they make their appearance. They are most plentiful on roots in a moderately damp situation. Their structure is that of hollow tubes, and they are actual outgrowths from the body of the root itself. They have a most fundamentally important function in the physiology of the plant — namely, to absorb from the surrounding soil the water which is required for the cells of the plant, and the dissolved materials in it. They come into closer contact with the soil than any other parts of the underground structures, and are destroyed when a plant is torn up. They are so delicate as to be almost impossible to be seen with the naked eye, and yet are not less important than any



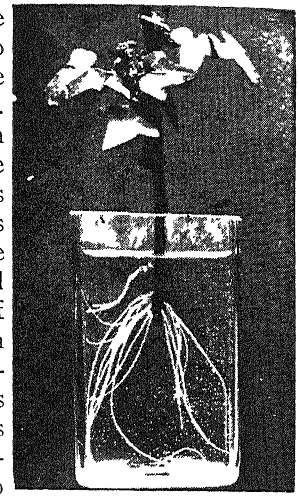
From Lyon s *Soils and Fertilizers*, The Macmillan Co.
THE SHALLOW SOIL THAT SERVES THE PINE

part of the plant. Everything that the plant gains from the soil reaches it through these root hairs. Only through them can moisture be taken in, and all that moisture contains (see illustration of root hairs on the next page).

The actual process by which these root hairs are enabled to transport the water and the soil into the tissues of the plant is that which we have already studied under



EARTH CLINGING TO ROOT HAIRS



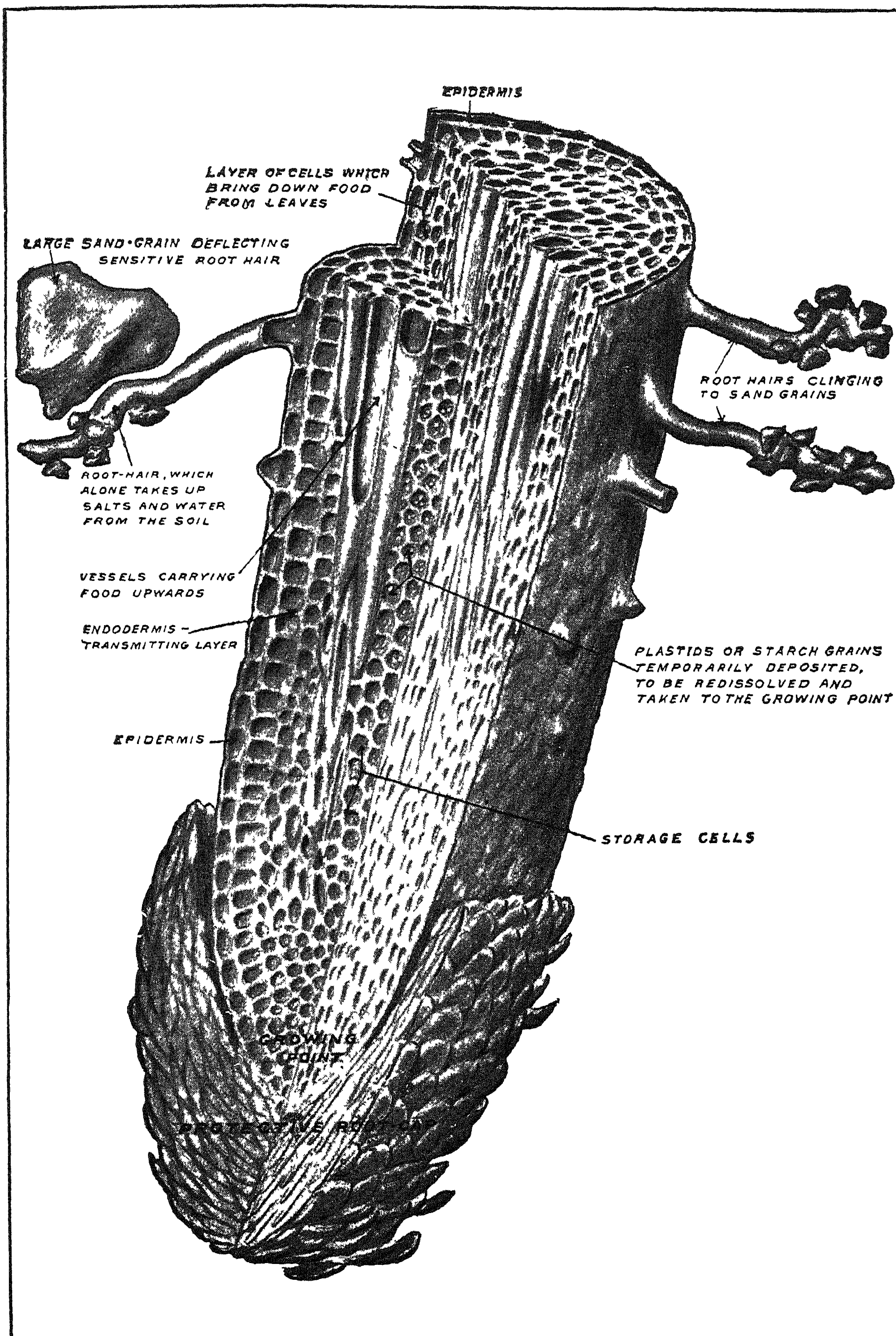
A YOUNG IVY-CUTTING ROOTING IN WATER

the name of "osmosis". It is only those cells on the root hairs which come into actual contact with the particles of the soil which do this work of absorption. The rest act as conductors. They move in such a way as to suggest that they are searching for the most favorable points where this absorption can take place, thus penetrating into the small spaces in the soil in which moisture is found Should they come to a particularly dense part of the earth, or a solid portion, they turn aside and grow round it. If they encounter large grains of soil they sometimes divide, growing round the grain, and, as it were, embracing it. The minute particles of the earth are found attached to these root hairs, and this attachment is produced by a sort of sticky secretion of the external layer of cells on the root hair. Not only, however, do these root hairs act as organs of absorption for the plant, but they are also organs of excretion. Thus carbonic acid passes out from the plant through them into the earth.

It should be noted that these hairs can only do their work in moist ground; and whenever the branches of roots have to make a choice, as it were, between a dry and a moist portion of ground, they invariably grow towards the moist part. This simple fact accounts for the many curious bends, and turns, and changes of direction which can be seen in almost all roots when they are exposed. An examination of any sufficiently deep cutting in the earth will show numerous examples of this fact. The root hairs are constantly perishing and being renewed, and always do they arise about the same distance from the growing tip of the root. They are the more abundant in plants which transpire readily, because in such plants there is a greater necessity to keep up the supply of moisture.

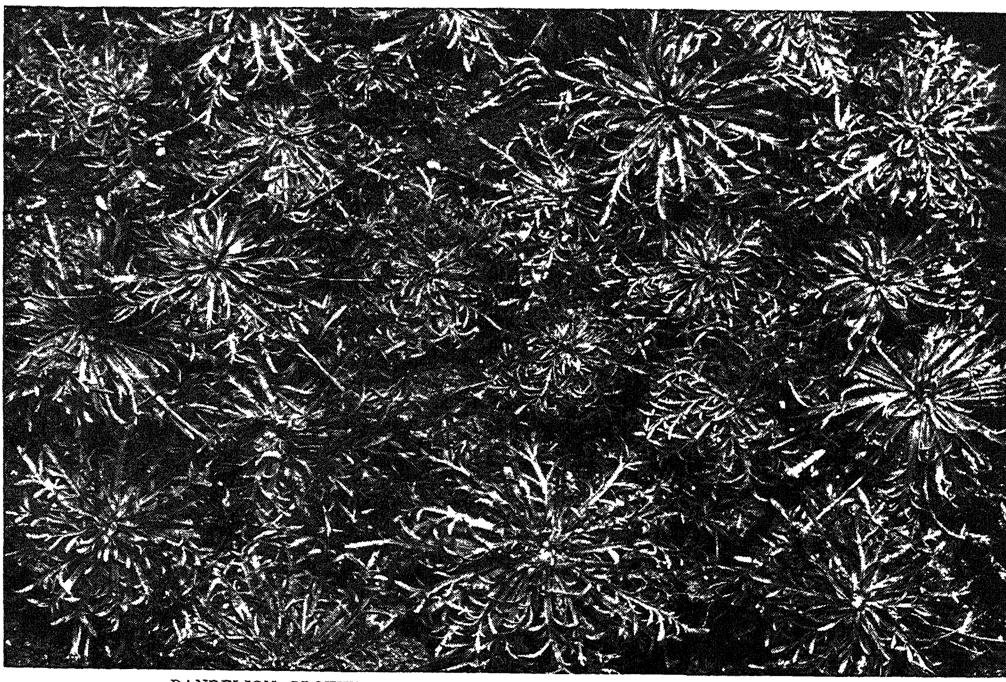
The root, the stem and the leaf are the three essential parts of the plant in connection with the physiology of feeding and breathing. We have discussed the part played in this function by the root, and we must now turn to the consideration of the second of these structures — namely, the stem, since the stem might be defined as that part of the anatomy of a plant which communicates between the root and the leaves, and enables them to work in harmony. It has also, of course, the very important function of elevating the leafy portion of a plant above the surface of the soil into the open air and sunlight, under which conditions alone leaves can best perform their work. The origin and the development of the stem we noticed in connection with the seedling. We must now learn something of the various appearances of stems and their structures, just noting in passing that there are certain groups of plants which have so evolved as to be practically destitute of anything in the nature of a stem at all. These so-called "stemless" plants find examples in the common dandelion, the white clover and many others, which lie close to the ground. This stemless character obviously makes for the protection of the plant, especially from animals which would otherwise feed upon it. Such plants can even be trodden under foot without suffering any very serious injury, and they are therefore enabled to withstand the struggle for existence under conditions which plants with long stems could not resist. As a matter of fact, however, they are not really stemless, but their leaves and flowers come off from a very short stem which scarcely emerges from the soil.

THE BUSY FACTORY WITHIN THE ROOT



This picture-diagram shows a root in section, with the various structures named. The cells in the root hairs absorb the moisture from the soil by the process of osmosis, and also secrete carbonic acid, while the cells within the root act as conductors for carrying the food through the plant and for storage.

Nevertheless, it is true that for the best performance of the functions of plants with a complicated structure some form of stem is required, and many and varied are the modifications found in the stems of plants to enable them to do their work under the different conditions in which they find themselves. True, the dandelion and the violet can flourish close to the ground, but most plants require to get some distance above the surface of the soil for their best development, and, indeed, there is evidently a keen competition among many plants to secure the most elevated place within reach. This gives the leaves the maximum of light and air. If plants be crowded together, one can easily observe the effort made on the part of the stem to carry its leaves as high as possible; and in thick woods and forests, where the surface of the ground is always more or less in darkness, we find this principle carried to its limit in the climbers and creepers which, throwing their growing stems from one branch to another, may extend for immense distances before they finally appear at the tops of the trees, and reach the air and light.



DANDELION GROWING ON A FOOTPATH, HEEDLESS OF MAN'S TREAD

It is these climbers and twining stems which best illustrate the special means that stems adopt for their purpose. Three points attract the attention. First, they produce adventitious roots at intervals along the stems, which are used as anchors to support the stem in its progress so far on its upward journey. These roots attach themselves to any suitable object that will retain the stem in position. The ivy plant exemplifies this as it grows up the side of a wall.

Secondly, an effort is made to fix the growing stem by means of special twining branches, or tendrils; and, thirdly, in some cases the entire stem twists about or round and round any supporting structures it can find, as is seen in the case of the hop.

Some of these special forms of stems offer most interesting points for the student of plant life. Thus we find that in those which climb by means of tendrils the tips of these structures move about in the air in various directions until sooner or later they reach something they can lay hold of. They then proceed to coil themselves round this support. The stem goes on

growing, and another tendril goes through the same performance, and thus the stem is anchored at various points. But, still more remarkable, the tendril, having coiled itself round its own point of attachment, may then grow into the form of a spiral coil between that point and where it originates from the stem, thus acting as a spiral spring and drawing the whole stem to the point where the contact of the tendril takes place. This interesting arrangement is seen in the bryony plant.

In the case of twining stems, the end of the stem, which is growing continually, revolves in a more or less circular manner, until it — just as the tendril did — finds some supporting structure around which it can coil. This is one of the most extraordinary examples of actual movements in plant structures that we have. It is excellently seen in connection with the hop plant, which, after twining itself round and round the pole which has been placed in the ground for that purpose, continues to make this circular sweeping movement after reaching the top of the pole The circle so described by the twining stem is about two feet in diameter. Another plant commonly seen in greenhouses, and known as the wax plant, moves in a still greater circle, of about five feet, and the tip of the stem can be calculated to move at the rate of about two and a half feet in the hour.

We may further note the fact that the same species of plant always twines round its support in the same direction. This direction, however, is not the same necessarily in all species. Some of these tendrils are modifications of the leaf, an example of which may be seen in the pea, where the terminal leaf, instead of being

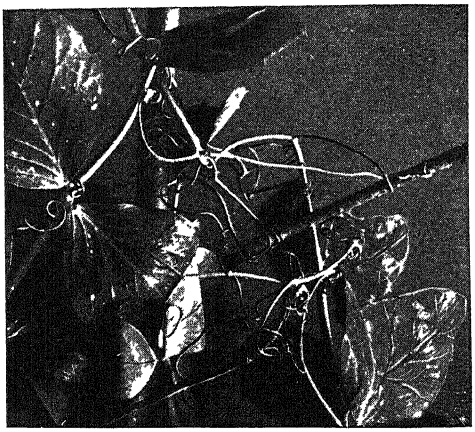
THE TWINING BINDWEED

THE TWISTING STEM OF HONEYSUCKLE

the usual green structure, is modified into a tendril — hence called a "leaf tendril" — very sensitive to anything with which it comes in contact, and readily coiling itself round any available point of attachment. In other cases the tendrils are modified branches of the plant itself, and this we see in the vine and in the passion-flower.

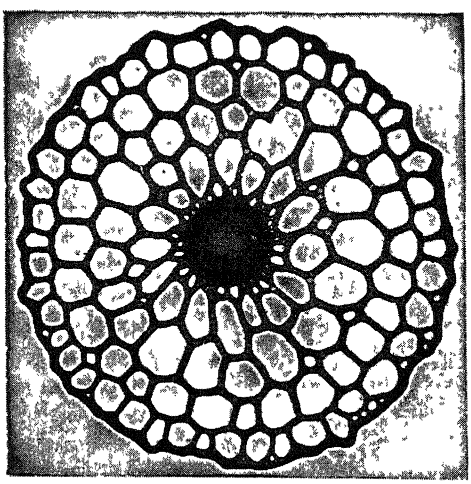
The following is a short summary of the different kinds of stems usually found. The "herbaceous" stem is the stem of most of our annual plants, as well as of many perennials. It is a soft structure, lasting

for a comparatively short time. Stems of a more permanent growth must become very dense in consistence, and this they do by producing true wood, and so are termed "woody" stems. Herbaceous



THE LEAF TENDRILS OF PEAS

stems are also composed of wood, but in them it is small in amount in comparison with the softer parts. The distinction between these two is really one of age, not of kind; it is a question of development.



SECTION OF MARE'S-TAIL SHOWING OPEN STRUCTURE OF STEM

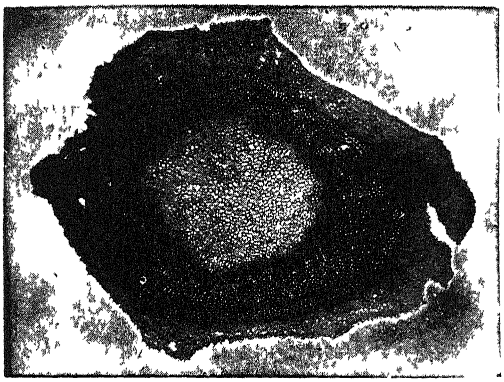
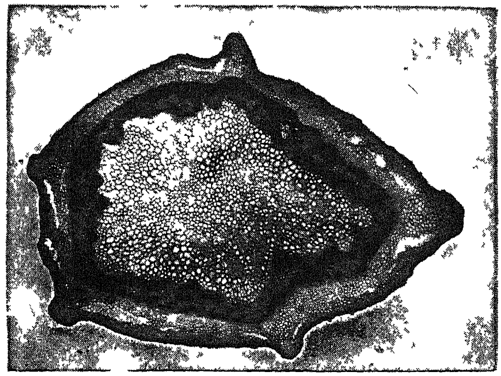
Thus a stem may be herbaceous in its upper parts and woody in its lower, as we find in the wall-flower

A well-developed stem of the woody type, lasting for a considerable time, is termed a "trunk", such as is found in trees and shrubs. The difference between these two is really one of branching, the tree trunk being free from branches for a certain distance above the surface of the ground. Its woody stem is a prominent feature. The shrub, on the other hand, does not show a very distinct main stem, and its branches, arising low down, are very much of the same size. If the stem is insufficiently strong to raise itself into the air, it is termed "prostrate", while if it develops means of supporting itself in other ways it becomes a "climbing" stem. These supports, as we have seen, are of various kinds, generally termed "tendrils", arising either from the stem itself or from modified leaves. Of the latter kind we have the common tropæolum, the clematis, the peas and the vetches In the case of the twining stem it should be remembered that it is the whole plant which is coiled round the support. The hop coils to the right, the bindweed to the left.

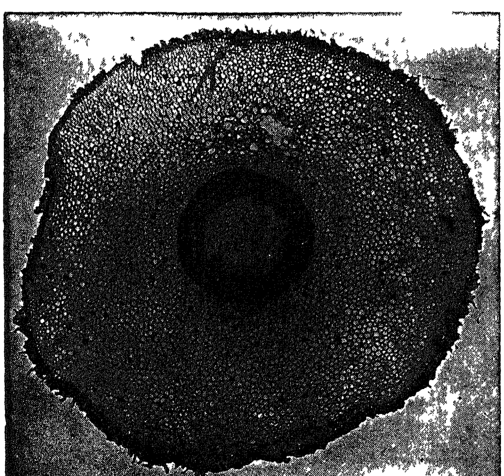
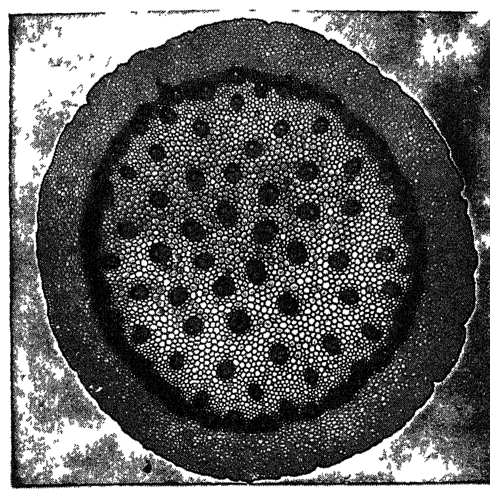
It is unnecessary here to enter into very minute detail of description concerning the intimate structure of roots and stems. The illustrations in this chapter have been prepared in order to show these points, and a careful examination of them will give the reader a better idea of their intimate structure than mere description.

We have only further to consider at this point what the living parts of the stem actually do, and how the labor of the whole stem is divided among them. This is best studied in the stems of trees. The pith, which forms so large a part of the stems in younger portions of plants, becomes comparatively unimportant later on, though it serves a purpose as a food storehouse. The medullary rays in shoots are the passages along which the moisture and the dissolved food are transferred across the stem, and they also contain stored-up food. The vessels, or channels, in the stem are mainly water-passages up which the moisture travels. The hard, dense portion of the heart of the wood serves the function of maintaining the erect attitude of the tree in virtue of its density. Other cells in the sap-wood, which also helps to support the tree, in addition carry water from roots to leaves.

The layer of cambium is that in which new growth takes place every year. But the most important part in connection with the inside of the bark is that in which lie the sieve-tubes It is through these that the digested food for the plant is transferred from the leaves in the direction of the roots Much of the nutrient material in the growing portion of the stem is collected by the green layer of the bark, but this process we shall have to consider in connection with leaves in a succeeding chapter.

TRANSVERSE SECTIONS OF THE SOFT AND HARD PARTS OF THE STEM OF A WALLFLOWER

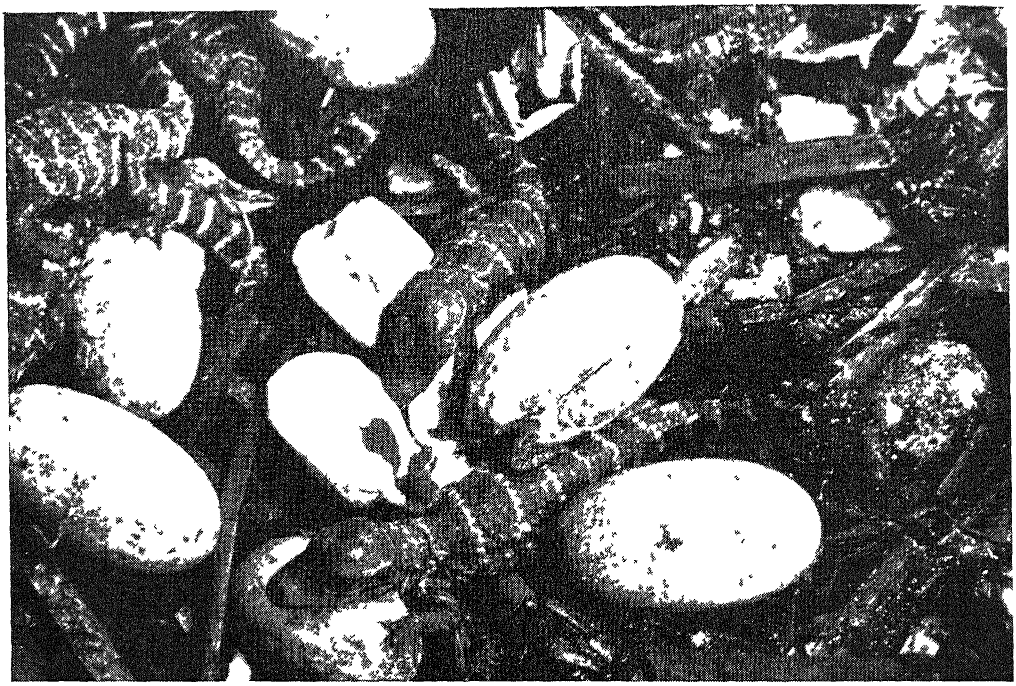



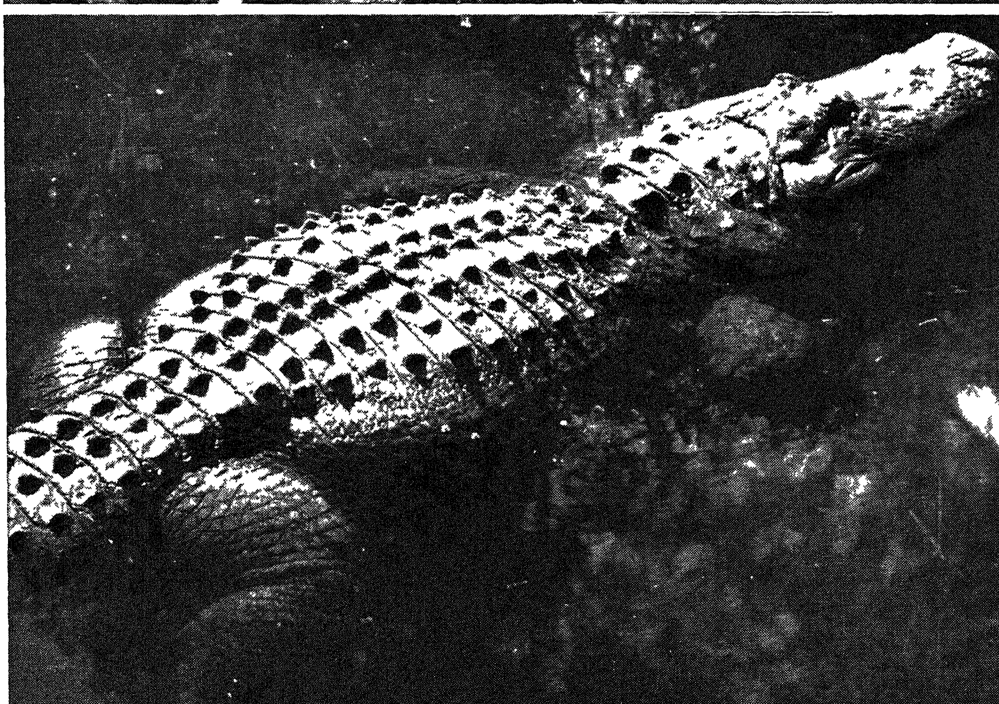
TRANSVERSE SECTIONS OF THE ROOT AND STEM OF BUTCHER'S BROOM

A considerable amount of water in the form of sap moves by the process of osmosis from the root hairs into the stem of the tree, and rises in the form of crude sap through the newest part of the wood. As a matter of fact, there is both an upward movement of sap, and, in addition, lateral transportation of the fluid from one side of the stem to the other The causes of these modifications of water or fluid in the stem have been dealt with in connection with the process of osmosis and the phenomenon of root pressure.

All the most important points in the foregoing paragraphs will be found to be easily understood if a careful examination be made of the illustrations in this chapter, showing roots and stems entire and in cross-section, and diagrams of structure. We would especially draw attention to those which show the different kinds of roots and the way in which the minute particles of earth cling to the root hairs to which they yield up their moisture and other nutritive elements. The other pictures show how these elements are transported throughout the plant.

ALLIGATORS, LARGE AND SMALL





Both photos, Hugo H. Schroder

Above: a squirming assortment of newly hatched alligator babies, crawling about the eggs that have not yet yielded up the little animals within them. Some of these eggs are whole; others have split, as they usually do before the alligator is hatched. Below: a full-grown alligator in a Florida creek.

ANIMALS IN ARMOR CLAD

Defensive Survivals from the Ages
When Jaw and Claw Ruled the Earth

THE CROCODILE AS A GRUESOME RELIC

EVERY order in life sets out upon its career as a traveler arming for a road beset by bloodthirsty brigands. The process is so old that life may be said to have organized itself into three campaigning groups. One makes attack its means of defense and its method of maintenance of existence. A second trusts to speed, to agility, or to that deceptive appearance which we call "protective mimicry". This, of course, is now the largest group, and is susceptible of infinite subdivision. The third great division lays on armor as if it were a garment.

Though placed third in our classification, this group is really a primitive one. When the early animals, waxing mighty in numbers and potent in strength, emerged from the waters to the margins of seas and rivers, and spread far over the land, and the fight for food necessitated the devouring of animal by animal, some defense was called for which ravening teeth and claws could not penetrate. We see today in the armored animals of our own time living relics of that gross and terrific past in which giant brutes, riving and tearing their living prey, parted the planet among themselves.

Nearly every group which can be traced back to its ancestors interned in the rocks is found to have attained either to nightmare proportions or to armor. Most of the animals that retained their armor went out of the plan of existence. Why so many should have perished, while others have remained to flourish in enormous numbers down to our own day, is a problem which considerations of space prevent us from discussing.

Armored animals are more numerous than at first appears, for many types of insects in their coats-of-mail — all the crustaceans, the bulk of the molluscs in their shells, the coral within its defense, the starfish in its limy walls, the snail in its wondrous shell — these are all armored as truly as are the mail-clad sturgeon and the heavily defended garpike, the coffer-fish, and the file-fish. But, numerous as are the animals which have survived by the use of material shield and buckler, they are in a minority as compared with those that have become extinct, yielding place to unarmored descendants for whom activity of brain and limb proved a better defense than the finest mail or carapace that nature ever designed. It will be of interest to consider the defenses and habits of some of the survivors and, neglecting scientific classification, include diverse types.

It is one of the delights of the anatomist to be able to indicate structural features common to birds and crocodiles, but the fascinating fact to the layman is the resemblance between the two in the matter of their birth. Among the members of the crocodile order we have animals which in point of length exceed all other terrestrial animals, snakes alone excepted. Some of them attain a length of between thirty and forty feet, and huge girth and bulk. Yet these monsters lay eggs — forty, fifty, sixty eggs to a nest. In the structure of the heart, and in the beginning of a diaphragm dividing the thorax from the abdomen, the crocodile is more highly specialized than any other reptile, yet it has not advanced to what we call the "viviparous stage".

There are reptiles — the vipers, for example — as there are certain species of shark, in which the eggs are hatched within the body of the parent, but the lord of all the reptiles, the strongest thing in armor, is hatched from an egg laid in an earthen nest, or in rotting vegetation underlying the bushes upon the verge of stream or swamp. Fancy a thirty-five-foot monster, capable of living hundreds of years, and of slaying horse, buffalo, rhinoceros and man himself, issuing from a little pit of sand as the product of an egg no bigger than that of a goose! This is a fact to carry the mind back to the dim and distant ages when fiends in animal form made life hideous.

ALLIGATORS JUST EMERGED FROM THE EGGS

The crocodiles have survived because they remained more generalized than other armored monsters. Their armor is of horny plates, extending from the head to the tip of the tail and, considering the mobility of the animal, this is practically the best form of armor preserved. The crocodile has one disability. Thanks to a merciful limitation, the brute cannot turn its head from side to side, but must charge in a straight line, so that a victim having the presence of mind to circle round the reptile can escape. But despite this limitation the group has long been lord of the places which it frequents. Fairly active on land, and equipped with formidable rending teeth, cunning, invincibly ferocious, and impervious to the attack of any living animal, the members of the order have thriven wherever climatic conditions have rendered it possible. They positively teem in the waters of Central and South America. The Amazon, in parts of its course, is as well stocked with them as a ditch is with tadpoles in summer. They are at once the scavengers and the scourge of the Ganges; they grow to huge size in the Nile, but are now in the lower reaches of the river accessible to the sportsman. They abound in certain rivers of China; they are the curse and horror of certain African rivers. They are one of the indigenous terrors of Australia. In tropical and subtropical climates, given the necessary river, estuary, lake or marsh, they have defied every sort of animate rival throughout their long career.

What has given them this great ascendancy, this hold upon life and power during the ages wherein life about them has changed like the moving color scheme of the kaleidoscope? Clearly armor has been of service to them. No animal can prevail against such an equipment. Added to this is the power of the animal to live either in the water or out of it, a circumstance associated with a highly important fact in regard to the gaining of food. It is not to be inferred that a crocodile can sleep under water day after day, or night by night, never rising to the surface. It is not a gill-breather, of course. But the beast is so fashioned that, while its entire body is immersed, the nostrils, elevated above the rest of the snout, remain free of the water and enable the animal freely to breathe while thus hidden. That is one means by which it is able to capture its unsuspecting prey. But the breathing process is peculiar in more than this respect. The windpipe is not open to the mouth as it is in other animals; it is continued into the nostrils, and can be entirely divided from the mouth. The consequence is that, seizing its prey and dragging it under water, the crocodile can breathe with its mouth open without hindrance from the water by which its tongue and jaws are flooded.

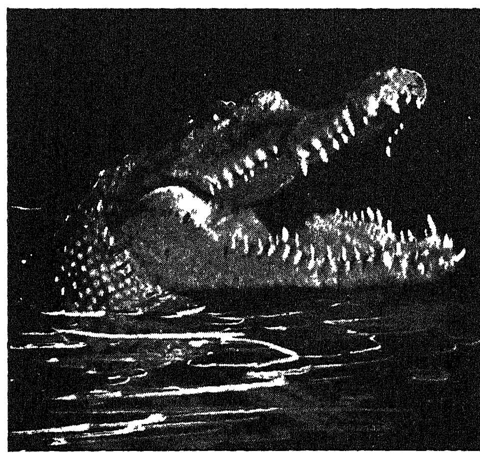
The victim drowns while the cruel teeth hold it under the stream, but the reptile, so long as the tip of the muzzle remains in the air, can breathe with ease. This is a marvelous adaptation to the life which this reptile of the world or waters lives.

The fact is that until the coming of powerful firearms there was nothing to check the advance of the crocodile. From certain points of view it was perhaps as well, for if it took toll of human life, the crocodile also acted involuntarily as a life-saver in that it has been for ages the great scavenger of the waters, consuming for preference the putrid bodies carried down by streams in flood which might otherwise have poisoned man's drinking-supply and spread disease.

So far only the generic name "crocodile" has been employed, but the order embraces half a dozen genera and nearly a score of different species. The caimans are restricted to Central and South America, and are so numerous that the pursuit of them has become an organized industry in Colombia, where as many as 30,000 skins have been exported in a year. Some of the animals attain a length of twenty-four feet, and a girth more than six feet; while their skins of mail, half an inch in thickness not counting the underlying bony protection, when spread out cover an area of as much as eighty to ninety square yards.

The species most sought, however, is the shorter, thick-headed caiman, whose length does not as a rule exceed ten feet; but as it yields excellent ivory in the form of huge teeth, as well as eighty pounds or more of fat from which is obtained an oil used by the natives for medicinal purposes in place of cod-liver oil, and the bones and flesh have a value to the agriculturist, there seems a future for the king of the reptiles very different from that dreamed by the natives whom he has so long terrorized. The caiman is called the alligator, but scientifically the alligator is a genus consisting of only three species; and the curious thing is that one of these, the Chinese alligator, is that which most nearly approaches the American caiman in structural features.

The best known of the alligators is that of the southern waters of the United States, called specifically the "Mississippi alligator". This reptile differs from the crocodile chiefly in the fact that its feet are only partly webbed, and in the shape of the snout which is broad and rounded at the end — not narrow and prolonged. The body is more massive and the weight greater. In the adult the color is blackish green above; but young ones are yellowish with black cross-bands. The nostrils are not elevated, and the alligators spend more time on land than do the crocodiles, lying for hours on some mud-bank basking in the sun; but even the biggest are very timid and quick to retreat to the water when alarmed. One rarely shows



THE TERRIBLE JAWS OF THE CROCODILE

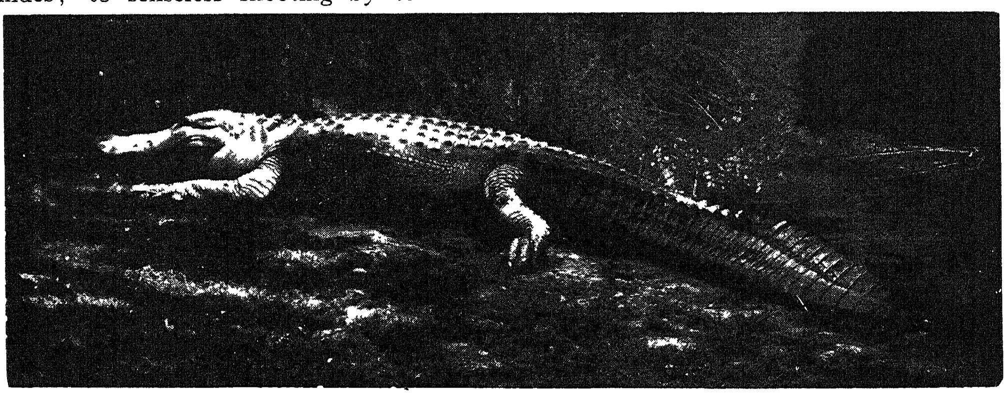
any disposition to attack a man unless he is in the path of escape. Ditmars tells us, indeed, that a man may with perfect safety go bathing in water inhabited by alligators, and feel assured that his presence has inspired the reptiles to place a substantial distance between him and themselves. Nevertheless when cornered, this reptile, which often exceeds twelve feet in length, fights with bold courage and is a formidable antagonist. Its great jaws and big teeth could bite off an arm or leg of a man, and its six or seven feet of tail hurled from side to side with amazing swiftness and force would kill a man with a single fair blow. Yet many are caught with great hooks and dragged ashore and killed, or are trapped in a noose

of rope and bound into helplessness by agile men who know how to avoid their rushes, and dodge jaws and tail. It is said that when a big angry fellow crashes his jaws together it sounds like a stroke on a bass drum. Young ones in captivity are often bad-tempered, but old ones, such as those in zoological gardens, become tame and are not feared by their keepers.

This alligator formerly was abundant in the coast rivers and inlets from North Carolina to the Rio Grande, and up the Mississippi and its tributaries as far as northern Louisiana; now it is confined to the rivers and swamps of Florida and the Gulf Coast, and its numbers are rapidly diminishing This is due to incessant hunting to kill them for the sake of their hides, to senseless shooting by tourists and passengers on river steamboats, and also to search for their nests to get young alligators to sell to tourists as curiosities. The result will be the extermination of the species within a few years.

The breeding habits of the alligator have been thus described by Dr. Hugh M. Smith of the U. S. Fish Commission: "The maternal alligator in April or May seeks a sheltered spot on a bank, and there builds a small mound. The foundation of the mound is of mud and grass, and on this she lays some eggs. She covers the eggs with another stratum of grass and mud, upon which she deposits some more eggs. Thus she proceeds until she has laid from 100 to 200 eggs. The eggs in the course of time are hatched by the sun, assisted by the heat which the decomposition of the vegetable material generates."

This takes about two months; and a few hours before the young are ready to come out they make a squeaking noise, when the mother comes and pulls the mound to pieces, enabling them to wriggle out. "As soon as they have chipped the shell, the baby alligators are led to the water by the mother, who provides them with food which she disgorges, showing much anxiety for their safety. At this early period of their existence they are exposed to many dangers, being a favorite prey of fishes and turtles." It has usually been stated that they grow very slowly, but Ditmars's specimens grew in five years to an average length of five and a half feet and a weight of 50 pounds. Their length of life is not known, but probably is less than heretofore believed.



A MISSISSIPPI ALLIGATOR, BELIEVED TO BE NEARLY 200 YEARS OLD

The prey of alligators is fish, water-fowl and such small mammals as go into the water or too near its edge, where the reptile lies in wait. It is taken under water to be drowned and eaten; and if too large to be gulped down at once, is shaken or torn to pieces before swallowing.

The alligator has a distinguishing peculiarity in its loud voice, unique among reptiles. The smaller ones make a mooing noise, like a cow; but big fellows roar like a lion, and on a still night may be heard for a mile.

The crocodiles proper are more widely distributed than the caiman or alligator, being found in Asia, Africa and tropical America. Livingstone had many unpleasant experiences with crocodiles, which he wrongly calls alligators, a name also given wrongly to the crocodile of India.

He tells how he saw one of his bearers suddenly seized by one of these brutes in the river Leeambye. The man kept his head, and when the reptile got him down to the bottom of the water, whipped out a serviceable dagger and stabbed his assailant behind the ear — the only spot in which one of these creatures can be instantly killed. But the blow must be delivered by a bullet. In this case the reptile was only wounded. Still, writhing with pain, it released the man and made off at a great rate. But it left wounds upon his thigh which the man would carry to the day of his death.

Certain African tribes have a morbid horror of the crocodile, and if one of their number be bitten or even splashed by such a creature, he is forthwith, with his wife and children, expelled from the tribe. One such unfortunate outcast engaged with Livingstone, but, fearing that the traveler would regard him with aversion and contempt, refused to tell the cause of his expulsion. But it was there, written in indelible characters by the teeth of a crocodile upon the luckless man's flesh.

This attitude of the Africans curiously suggests a survival of animal worship which has its counterpart in India, where terrible loss of human life results from the gharial (incorrectly written "gavial") and the ferocious estuarian crocodile, a brute which ranges from India, Ceylon and Burma to Australia. It is the habit of a certain type of mind to worship the powerful and terrific. Grant Duff found a temple erected in India that had been dedicated to cholera.

Naturally, then, the frightful crocodile is regarded as sacred — as it was in ancient days in Egypt. A typical example is afforded by the little village of Mugger Peer, not far from Kurrachee. Here is a ford at which it was noticed that men, women and children, crossing with their burdens at eventide, were wont to disappear. So a watch was at last set and it was found that the crocodiles which infested this part of the river were the offenders. The government was petitioned to intervene not to destroy the animals whose crimes had made them sacred, but to restrain them. So the crocodiles of Mugger Peer are to this day restrained — inclosed, so far as this ford is concerned, by high walls. But the largest and most ferocious brute the people worshiped with particular fervor. He was the rajah of the crocodiles, they said; he must be left at liberty. And this course was agreed to on the condition that a sentry kept guard to see that the reptilian rajah did no harm. And a little temple has been erected at Mugger Peer whose congregation make it their business to feed the crocodiles that they may not suffer hardship for the loss of the human flesh which they formerly had without stint.

Of course, the tables can be turned upon the crocodile; not only may his skin and his fat be utilized — his flesh *can* be eaten. Dean Buckland was not the last to prove that fact, for after slaying and dissecting a couple of the monsters, from one he cut a steak, and made a dish of it for a dinner party. The guests decided the flesh was excellent, resembling tunny or sturgeon.

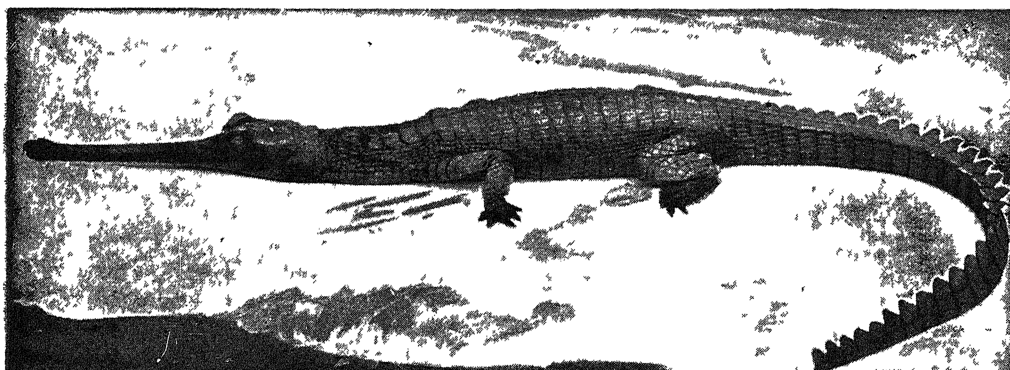


Photo C. R. Walter

THE GHARIAL CROCODILE, WHICH CAUSES TERRIBLE LOSS OF LIFE IN INDIA

Though its brains are of the most contemptible order, yet there is deadly cunning in the crocodile's ways as when, seeing a man upon the bank of the river opposite to that on which it rests, it plunges like a fury beneath the water. All is silent, but a keen observer may detect a line of ripples advancing across the water. The brute is rushing along the river-bed to seize the man, who has lost sight of it. The adult crocodile has no enemy to fear except the man with the gun. It has only one friend, and that is the black-backed plover, which, walking unconcernedly into the open mouth of the animal, scavenges without molestation, and warns the reptile on the approach of man with its cry of "Zic-zac" from which the bird takes its name.

Before taking leave of this order we ought to recall the fact that the gharial and the alligator formerly abounded in Europe. This is the more notable from the fact that nowhere on earth today can the two genera be found together One is restricted to tropical Asia, the other to the warmer latitudes of America, and both are excluded from Africa in whose waters only the crocodile is found As Owen has written, not one representative of the crocodile exists naturally now in Europe, yet every form of the order once flourished in close proximity to the others in a land that now forms part of England

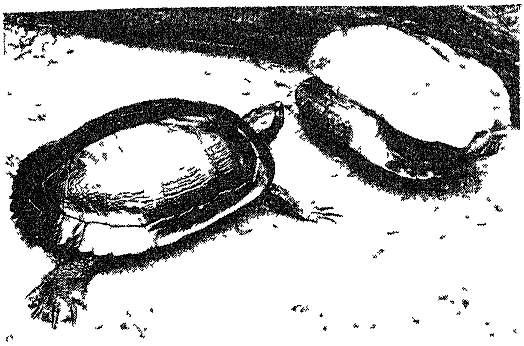
We shall meet other armored reptiles at a later stage, but here we pass to an extraordinary development of the defensive principle upon totally different lines.

The crocodiles may be likened to armored trains, but the tortoise family are rather perambulating forts — minus guns. We mourn, and rightly mourn, a lost species but this family is witness to the fact that contemporary marvels, so long as they are plentiful, receive not a tithe of the attention that they merit. It is a plain fact that there is not in existence today, nor embedded in the matrix of the rocks, a more extraordinary animal than the tortoise. Here defensive development has reached its most fantastic expression. There is something almost uncanny about the appearance of this animal.

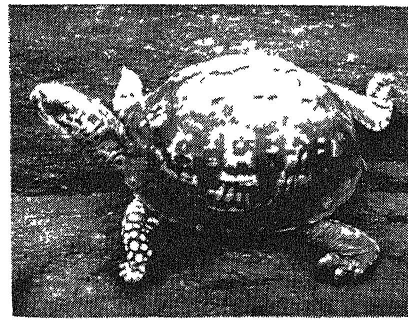
It began, we suppose, upon lines followed by crocodile and many an extinct monster of the sea and land, with a leathery hide in which were embedded various nodules of bone From these has been evolved one of the most wonderful armaments ever devised. The nodules became plates of bone welded into an impregnable carapace Superimposed upon this has arisen the beautiful overshield of horn To attain this the tortoise has, as to most species, sacrificed the skin of its trunk and the underlying muscles; it has forfeited all elasticity of vertebræ between the neck and the tail, and fused these vertebræ into an immovable hollow column of bone, incorporated like the ribs into the fabric of the carapace It has gradually thrust collar-bone and hip-girdle out of place, so that in the adult these now lie not outside and free of the ribs, but within the cavity which they form. Teeth have gone, and a bird-like beak remains. Breathing is conducted by specialized organs; and in some of the water-tortoises the reptile is developing a fish-like method of supplementing its supply of atmospheric air by extracting oxygen from the water by means of special areas richly charged with blood vessels over which a supply of water constantly washes so long as the creature chooses to remain beneath the surface.

As we all know, there are giants even among tortoises. They were formerly abundant in India, Egypt, North and South America and in parts of Europe, but the advent of man was too much even for the ultimate height of animal armor, and their range became restricted to certain oceanic islands, such as the Seychelles and the Galapagos, where they proved so attractive a diet to mariners that they have been practically exterminated. The survivors should be preserved with care, for man will never again see another such natural marvel.

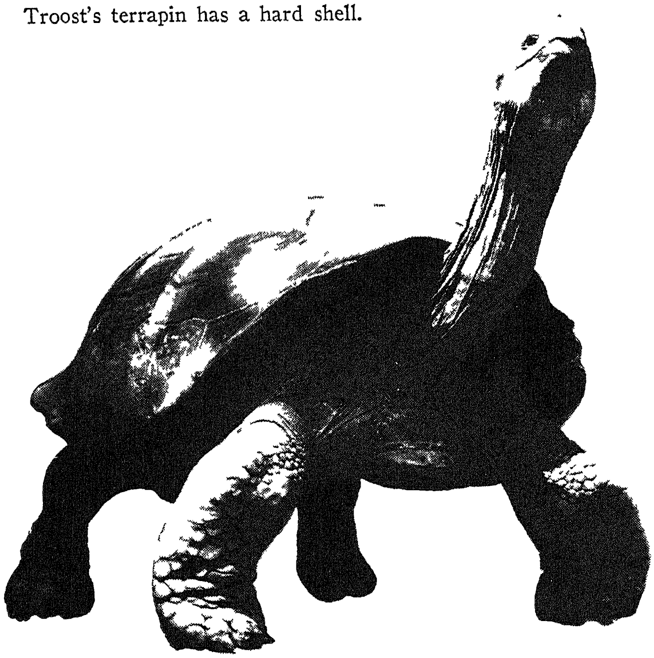
It is common knowledge that a tortoise is one of the longest-lived of animals. One died recently in captivity that was believed to be between four and five centuries old. How long they can live no man knows. The question arises, then, how do they continue to grow for such a length of time without casting their armor?



Troost's terrapin has a hard shell.



The common box turtle.



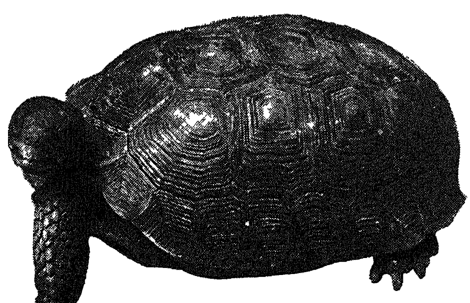
The giant Galapagos tortoise.

THE TURTLES

The turtles are survivors of a numerous group that flourished during the Age of Reptiles The animals are often divided into three classes: turtles proper, living chiefly in the water; tortoises, living on land, terrapins, the fresh-water, hard-shell species used for food.

All photos, N Y Zoological Society

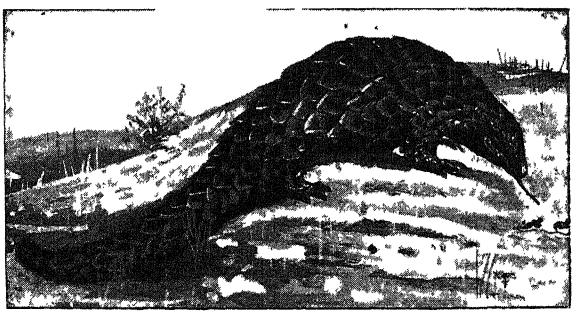
The striking camel-back turtle.



The desert tortoise.

The scheme of armament is never broken. The bones of the carapace are not one indivisible mass, but are sutured beautifully in such a manner that growth and expansion continually take place. The fortress grows with the garrison. It really is a fortress in the true sense of the word, for there are tortoises that have the lower half of the protecting armor hinged so that at will the head can be inclosed as by an ascending portcullis, while others are similarly defended both fore and aft.

Even so well accoutred a creature as the tortoise must find food; and the stress of life drove early members of the group into the water, where turtles and water-tortoises developed. It would spoil a city gourmand's appetite, perhaps, to tell him that his favorite dish is reptile broth, but his soup is only the stew derived from boiling a sort of water-tortoise which we call a turtle. In this family the legs have become flappers and, correlated with the carnivorous diet, a more formidable beak has been evolved, with which a turtle can snap off the fingers of an incautious man's hand as easily as a land-tortoise can cut a crisp lettuce-leaf. The most formidable of these are the snappers and the alligator turtle, one of the latter having been known to bite a piece out of an inch plank. The tortoise-shell of commerce, by the way, is derived from a turtle, the hawksbill. Disgraceful barbarity was formerly practised in procuring this substance, the shell being burned off the back of the living reptile, but happily that abomination has long been banished and the trade purged of cruelty.



THE SHORT-TAILED PANGOLIN

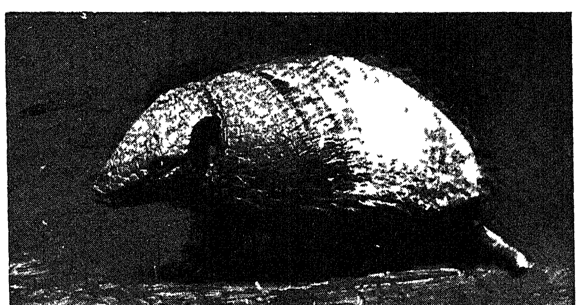


Photo Lewis Medland

THE HAIRY ARMADILLO

When Frank Buckland was made to pay three shillings and sixpence for the carriage of his monkey which, according to railway regulations, was a "dog" he asked the porter what he must pay for a tortoise. "That's a hinsect and goes free," answered this prime naturalist. What would the glyptodon have been declared in such a court? It was a mighty beast, in a vast bony covering at least six feet in length, and of tremendous weight. Most of us would have been inclined to describe it as a reptile, but in reality it was a mammal, and it has left collateral mammalian descendants in the armadillos of our own time. The glyptodon, the biggest armored mammal that ever lived, was too massive, too immobile. The armadillos have improved upon the older method; they have their fine coat of bony mail, covering the upper parts from the snout to the tip of the tail, but they have their armor hinged, as it were, so that these sturdy creatures can curl up into a ball of armor as neatly as a hedgehog.

Their near ally, the pichiciago, lacks this advantage and, though well armored from buttocks to snout, must remain at full stretch when attacked. There are several species of armadillos, the type culminating in the great armadillo, a mammal marvelously armored, three feet in length, and clad with claws formidable enough to suggest an easy passage into the graves which the animal is accused of robbing.

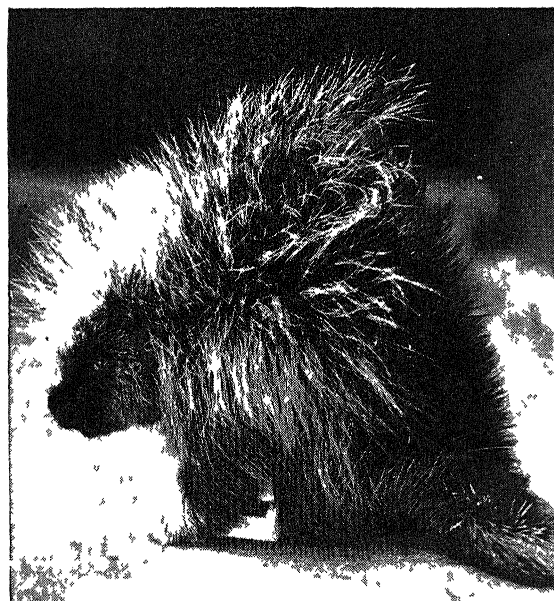
Two other styles of armament come to mind in those borne by the echidna and the pangolins, the latter well described as animated spruce-cones with head and legs

attached. They are toothless insect-eaters, ants being their chief source of food; but, as prenatal evidences point to ancient possession of teeth, it is believed that the pangolins arise from the same stock as the armadillos.

Indeed, the name of the echidna, "spiny ant-eater", declares its characteristics. But though warm-blooded, it lays eggs, and hatches them in its pouch, and then suckles the young — so little and yet so far is it beyond the reptile.

In the armament of the echidna we advance towards another scheme, that of the porcupines. We have finished with plates of bone and horn, and have reached the defense which furnishes means of aggression. Porcupines, whose name really means "spiny pig", are common to both the Old World and the New, and are rodents. They are supposed to be the counterpart in the lower creation of the assegai-throwing Zulu, for nothing will shake the popular belief that the porcupine, when he is annoyed, stands still and bombards his enemy with his quills. Whence the motive-power for the discharge of the projectiles could be derived the authors of the legend omit to inquire. The Canadian porcupine, which has shorter spines than those of the typical group, has these implements short and loosely attached to the skin, so that in a scrimmage they easily become detached and fixed in the flesh of an antagonist. But in the larger porcupines of the Old World — they are found both in southern Europe, in Africa and in tropical Asia — the quills are longer and stouter, and are brought to bear by a wily device.

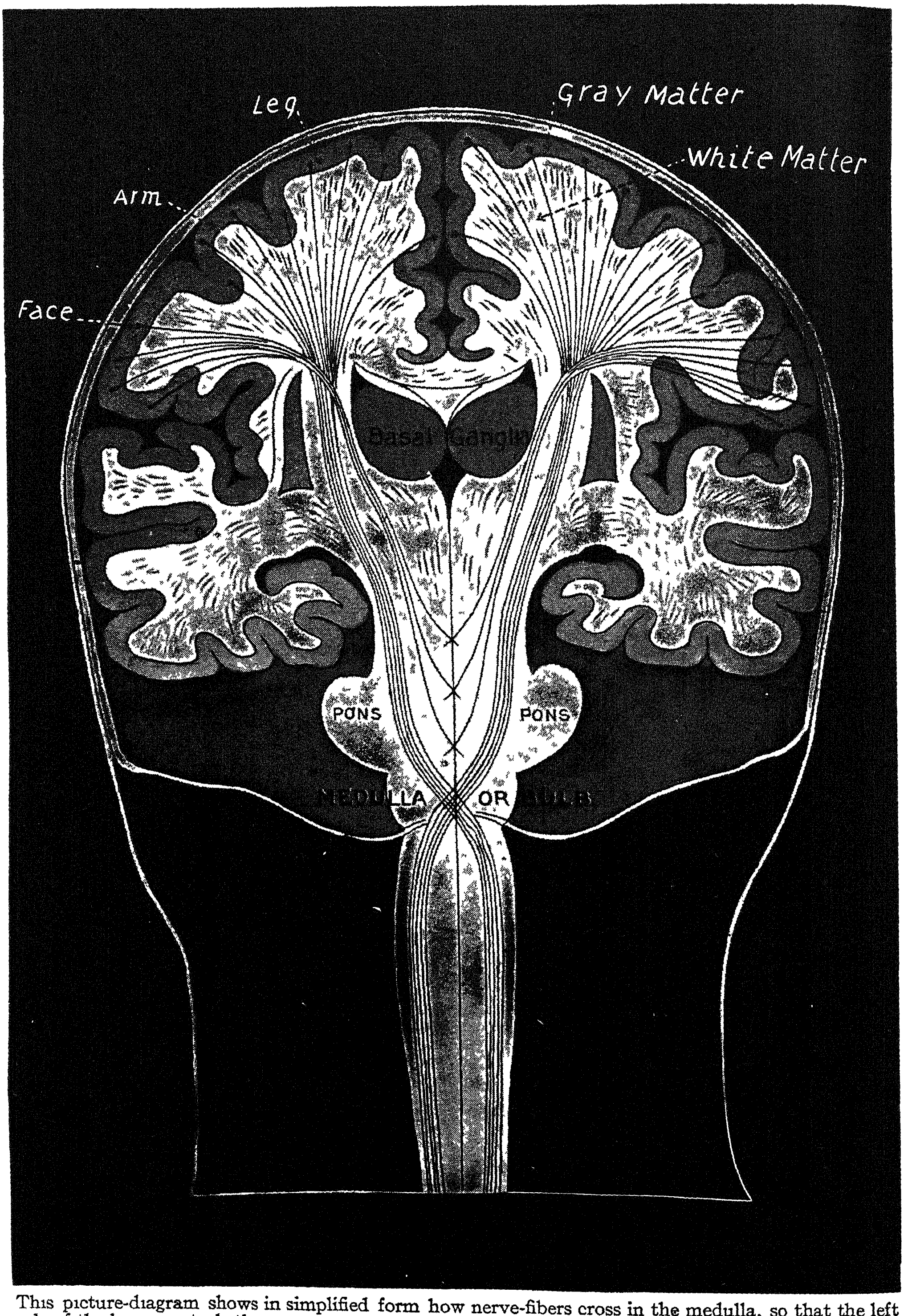
The porcupine, upon being attacked, keeps his hindquarters toward the enemy and, making a sudden dash backward at him, thrusts his quills deeply into the enemy's flesh. Should any of the quills be loose, they may then remain in the hide of the antagonist, and so support the old story of assault by a battery of quills. The Brazilian tree-porcupine has its spines hidden by hair but, as they are barbed like the spines of certain cacti, no man handles this animal with bare hands. It is a curious but effective defense, a device resembling that of a man the hair of whose head was sown with fish-hooks. The defensive-aggressive quill has succeeded, too, for porcupines are widespread and many. But then the land-tortoise, most immobile of all nature's armed host, is multitudinous in numbers. So are the Crocodilia. Not all the best-defended have perished of inertia.



Photos, N. Y. Zoological Garden

The left-hand picture shows the hairy tree porcupine; the right-hand picture, the yellow head western porcupine. The porcupine is a rodent.

MESSAGE-CARRIERS FROM BRAIN TO BODY



This picture-diagram shows in simplified form how nerve-fibers cross in the medulla, so that the left side of the brain controls the movements of the right side of the body, and vice-versa. These fibers convey the impulses from the surface of the brain to cells in the spinal cord, and thence to the muscles

THE SUPREME ORGAN OF LIFE

The Design and Structure of the Brain, and the Known Functions of Its Component Parts

A SUMMARY OF EVOLUTIONARY CHANGE

WE have already studied the lungs, the liver, the heart and many other organs of man, and have learned that they exist for his nervous system, and, above all, for the supreme organ that life has created hitherto — that is, the brain of man This organ is worthy of very careful study by means of dissection and the microscope, for we should not forget that for many long ages, when men argued without looking, they believed that the function of the brain was to cool the overheated vapors arising from the heart — a physiological theory which is still contained in many modes of speech, as when we say that we are "in high spirits".

Only the anatomy of the brain can afford us the clue to its function, and can justify those views of its essential purpose which have already been suggested We are encouraged by the fact that this organ *must* hold the key, if anatomy holds it at all, to man's place in the world It is the only characteristic organ of man, being far larger and more complicated in him than in any other creature It is absolutely the largest brain in the world, even including the whale and the elephant, and, relatively to man's size, it is larger and more exceptional still.

Further, we know that the size of this organ has been increasing, along the vertebrate line of dawning intelligence, for long ages past. If we compare any branch of modern mammals, for instance, such as the horse, the ape, the dog with their remote ancestors, we find that the tendency has always been for brains to beat bulk, brains always increasing while bulk very often decreases. This is the organ of intelligence, and therefore above all the organ of man. It is the highest achievement of organic evolution We marvel, naturally enough, at the beauty and powers of bird and beast We almost cower beside the skeleton of the whale We are staggered at the size of early reptiles and mammals, such as those whose skeletons can be seen in many museums We envy the dignity and longevity of the mightiest trees of the New World, and the superb chemistry, incomparable in its way, of the green leaf anywhere, but each of us carries inside his skull, and is using at this moment, an organ, a material object, a piece of machinery, which beggars everything, extinct, or extant, that Life has ever achieved since Life began.

The development of the brain in each of us is to be noted. At a very early stage in the human embryo there is a long groove formed along the middle of the back — just where the backbone will some day be This groove comes to be roofed in, thus forming a long, closed tube, lined, of course, with cells from the surface or ectoderm of the embryo This is the nervous or neural tube The cells lining it become, or give rise to, nerve-cells From these there spring the innumerable nerve-fibers which pass to all parts of the body for various purposes. The back part of the tube, which is the lower part in the erect attitude, remains small and straight. It is the spinal cord, with its tiny central canal, which is the original tube that was formed in the embryo when the neural groove was closed in. Around its central canal we see a multitude of nerve-cells, called the "gray matter" of the spinal cord, because of their appearance. Outside them is a quantity of "white

matter", consisting of nerve-fibers, running up and down in the spinal cord, connecting one part with another. The nerve-cells in the spinal cord are almost wholly concerned with the sensory motor arc which we have already discussed, and upon which psychological theory has asserted the whole of the nervous system to be based. Of all this, which is simple in essence, and is not characteristic of man, no more need be said, except to observe that from each segment of the spinal cord there runs, on each side, a nerve with two roots, and that, as Charles Bell discovered early in the last century, the front or anterior root is wholly motor, and the back or posterior root is wholly sensory. This discovery really laid the foundation for our modern understanding of the nervous system.

The astonishing development of the great brain in man

But as the embryo develops, the head end of its nervous tube develops in marked contrast to the posterior end. It begins to form a series of more or less hollow bulbs, with constrictions between them. The tube is still a tube, with a single cavity, continuous from end to end, but at the head end this tube now consists of quite large chambers, and the nervous tissue around them is very greatly thickened. At one time we can distinguish five of these swellings, at another three. They become squeezed and compressed against each other, as they enlarge, for they have somehow to find room in the skull. But the front bulb is far and away the largest, and there is no room for it any further forward. It has no choice but to fold backwards on itself, so that it comes to lie upon all the other parts of the brain. This front bulb, which undergoes such astonishing development in man, forms the cerebrum, which constitutes by far the greater part of the brain in man, and is its characteristic part. The first appearance and increasing development of this foremost swelling of the front end of the nervous tube, which is the physical counterpart of man's intelligence, can be traced from the earliest vertebrates to man.

The skull's accommodation for the brain a rough measure of mental capacity

In humbler forms the cerebrum is a mere projection from a brain which mainly consists of the nervous centers of vision and smell. Later it has grown, until it begins to turn backwards in order to find room, and thus hides part of the older brain from view.

This process continues until, in the highest animal brains, those of the anthropoid apes, the cerebrum hides the greater part of the rest, when looked at from above. But in man the cerebrum is even larger. The whole of the rest of the brain, with the spinal cord and the sympathetic nervous system thrown in, is dwarfed by it; and when we look down upon the brain we see nothing but cerebrum, all the older parts being hidden and well overlapped by it.

The great size of the brain is indicated by the great size of the skull or cranium of man. The peculiar development of the cranium is forwards, but it is no less notably developed sidewards and upwards, all to accommodate the mighty cerebrum of man. The study of the cranium, or craniology, thus assumes a special importance. The cranium varies widely in capacity in different individuals and races. Skulls can conveniently be estimated as regards capacity by filling with small shot. There *is* a correspondence between skull capacity and brain development, but it is so rough that we must ignore it, though its general significance, when we compare brains and crania, from the fishes upward, is obvious. The attempt to find detailed correspondence between external cranial form and brain functions is, however, hopeless. for reasons already stated.

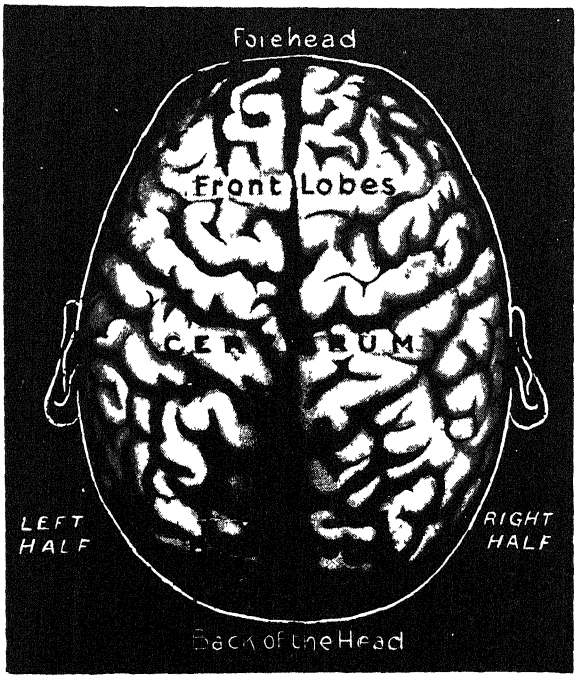
The evolution of the overlaid cerebellum, or little brain

But first of all we must look at the lower parts of the brain, which are essential to life, and indispensable for the operations of the intelligence, though none of them is characteristic of man. Their study in anything like detail is inexhaustible, but the main facts are simple enough.

Note that, according to anatomists, the brain ends at the level of the *foramen magnum* or "great hole" in the base of the skull, where, if the brain ends, the spinal cord begins. The lowest part of the brain is, however, none other in structure than the uppermost part of the spinal cord, and since it is slightly larger it is known as the bulb, or *medulla oblongata.* Above this part we come to another, still continuous with it, which is called the *pons,* or bridge, for a very good reason. First, it communicates between the cerebrum and the bulb and spinal cord. Second, it communicates from side to side between the two halves of a very remarkable part of the brain, calle l the *cerebellum.*

The cerebellum, or little brain, is easily the largest part of the whole, after the cerebrum itself. It resembles the cerebrum in various particulars but its surface is not so irregular and its markings are more parallel than those of the cerebrum. Its nerve-cells, or gray matter, are on the outside, and its nerve-fibers, or white matter, are on the inside. Its outside is broken up by very deep grooves, so that the surface is really much larger than it would otherwise be, and so its gray matter is proportionately increased. In all these respects the cerebellum resembles the cerebrum, though the breaking up of its surface is much more simple and regular, so that it has a kind of series of leaves, as the accompanying pictures show.

The cerebellum also resembles the cerebrum in the very important respect that it is growing in the course of evolution. It is of unique size in man, but it has also been growing, like the cerebrum, along with the development of intelligence in the course of vertebrate evolution. It is really a very large organ in man, occupying an extensive part of the back of the skull; and there is no better testimony to the amazing development of the cerebrum than that it can completely cover this greatly developed cerebellum, as it does. We may foresee that there is a problem here which merits much further study.



THE BRAIN, SEEN FROM ABOVE

If the upper part of the skull of a man be removed, as in this picture, there would only be seen the cerebrum, or new brain, which has developed so greatly in man that it completely covers the cerebellum.

Packed together at the base of the brain, underneath the cerebrum, and therefore invisible until the brain is taken apart, we find some large masses of gray matter, which are called the basal ganglia of the brain. Their detailed names need not concern us. But we must now try to state the functions of the various parts of the brain that we have named, for there only remains the incomparable cerebrum itself, with which we must hereafter be almost exclusively concerned in the following pages.

The medulla, or bulb, and the pons are simple enough as to function. Like the spinal cord, of which they are really the upper part, they contain a number of nerve-fibers or white matter, running up and down, and, in the case of the pons, also running across. But here we observe a unique and astonishing fact, which no one has yet begun to explain in any credible way. It we trace the nerve-fibers in this region, we find that a great strand of them, the greater number, indeed, cross

over from each side of the body to the other. Why they should do so we cannot say, nor whether the fact may ever give us, perhaps, the key to the historical origin of the central nervous system of vertebrates. But there is the evident fact; and its consequences are no less evident, for it means that, in short, the right side of the cerebrum masters the left side of the body, and *vice versa*. A vast range of knowledge of health and disease, and a great series of possibilities for surgery and for the localization of maladies of the brain, depend upon this simple crossing over of the nerve-fibers from one side of the body to the other in this region.

The bulb and pons, as well as the spinal cord, centers of important nerves

But, like the spinal cord, the bulb and pons also contain within their substance a number of groups of nerve-cells, which are arranged in a series of pairs. These are the centers from which proceed twelve pairs of nerves, which have a variety of functions. These pairs of cranial nerves, as they are called, run to (or from) the nose and the eye, control the movements of the eyeballs, run to (or from) the ear and the organs of balance, run to the muscles of expression, the tongue, and even to the heart and lungs and many of the organs in the abdomen. These last, the organs of the chest and abdomen, are all served by the tenth pair of cranial nerves, which are therefore called the *vagi*, or wandering nerves.

The details of the cranial nerves do not concern us here, but it does concern us that certain of these groups of nerve-cells club together, as it were, according to the destination of the nerves which run from them, so as to form "centers" for certain special purposes of great importance. This is especially true of the bulb, where, as we already know, are found the center that controls respiration — the so-called *punctum vitale*, or "vital point" — the various cardiac centers, the vaso-motor center that controls the size of the blood-vessels, the center for swallowing, a center that may somehow control the proper utilization of sugar in the body, and others besides.

The oldest part of the brain the part least easily endangered

Obviously, therefore, though this is the smallest part of the brain, it is of great importance. It is the oldest part, containing the ancient centers for the control of the ancient functions discharged by organs as old as the heart and lungs. Its stability is great. All manner of poisons and degenerations, senile and other, will affect the later, higher, more delicate parts of the brain, according to the well-known rule of evolution, "last to come, first to go", but the bulb will remain. A man must be desperately drunk before his bulb is affected and his breathing is endangered, though that is the mode of death from acute alcoholism. Insanity or senility may have practically ruined the cerebrum, or, indeed, in idiocy the cerebrum may never even have developed, but the bulb will remain intact, maintaining the purely animal life, though there be nothing else to boast of. Hemorrhage, also, into the bulb and pons is very rare — unless the base of the skull has been broken — and their blood-supply is very secure. The function of the cerebellum has long been highly obscure, and this organ has been deposed by modern science from the somewhat higher place which used to be given it. In the past, men located emotions of various kinds in the cerebellum, including love and hate. But we now know that it has nothing to do with such things.

The cerebellum the organ of balance and mechanical accuracy

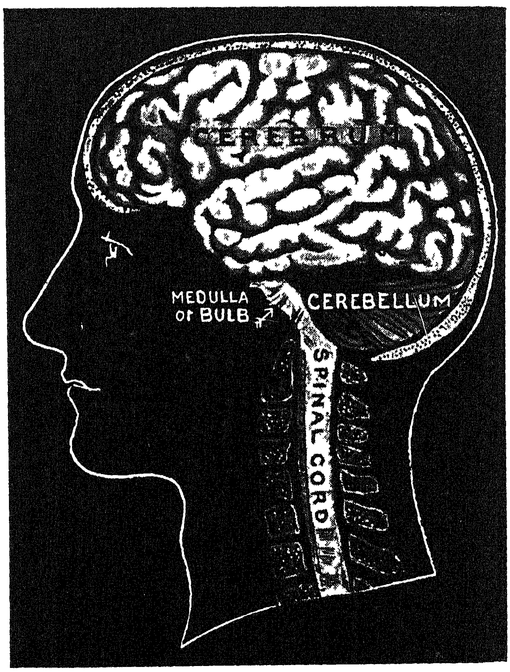
It is, above all, the organ concerned with our control of the body, as regards its balance, its movements, and its muscular habits and aptitudes. If we recall the modern interpretation of the human brain as a whole, that it can learn any habit, make any machine, perform any action, construct *new* motor mechanisms, unlike the brain of any animal, we may realize why the cerebellum is so large in man, and may even realize that, notwithstanding all we have yet to say about the cerebrum, man would not be man even without his cerebellum. In its ordinary

uses, this is the organ of balance. Thus a drunken gait is due to cerebellar poisoning, and such a gait in a sober person is the recognized sign of "cerebellar ataxia", which helps the neurologist to localize a tumor or other malady in that organ. But many other creatures have as much power of balance as man has, perhaps; and we must not suppose that this function is all or much of what the cerebellum achieves, though certainly this is the organ that the dancer, the skater and the tight-rope walker must educate above all.

It is, we may suspect, the organ that forms new motor mechanisms within the body. When we learn not merely to walk, but also to write, to talk, to play the violin and the piano, to sing, to paint, to sew, perform surgical operations, etc. — the list is endless — the cerebellum is being educated; and man has enough to his varied record of achievement for us to be assured that his cerebellum can learn anything he wills it to learn.

He can do what he was born to do; he can improve on this, and add dancing and skating to walking and running, merely by improving his capacities of balance. But he can do more. He can invent and construct absolutely new motor techniques, like those of the pianist or the surgeon, for his own special purposes; thus we see why his incomparable cerebrum needs an incomparable cerebellum, and why their evolution has proceeded side by side.

The uses of the basal ganglia are not very easily defined. They are very specially connected to nothing in particular, it would seem. Here is a great and complicated mass of nerve-cells, lying at the base of the brain on either side, which are not the obvious "centers" for anything. We do not find pairs of nerves emerging from them, as from the parts beneath them — the pons and the bulb. Nor do we find what the cerebellum shows so clearly — great numbers of nerve-fibers definitely proceeding from cells, and going to definite places. We find fibers from the cerebellum definitely running long distances in the spinal cord, for instance, and forming connections with both sides of the brain in all of its parts. But the nerve-cells which exist in such numbers in the basal ganglia do not send bundles of fibers to various parts in this fashion. They are not motor, like so much of the gray matter we have seen already, from the spinal cord upward, for no motor-nerves whatever spring from them. Neither are they directive and supervisory of motion, as the gray matter of the cerebellum has now been proved by scientists to be.



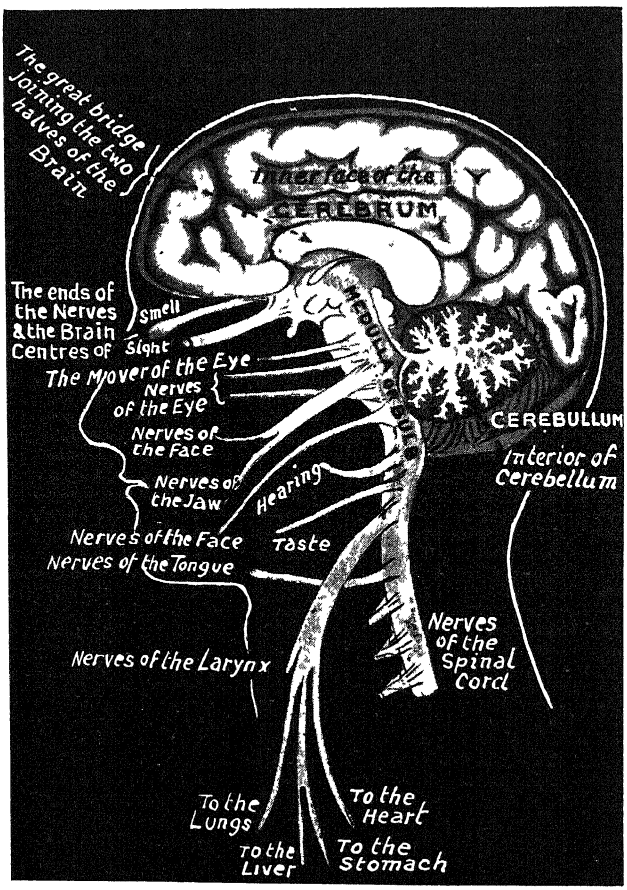
SIDE VIEW OF THE BRAIN

This diagram shows how the brain lies in the skull and the relative positions of the much folded cerebrum, the cerebellum, the bulb and the spinal cord.

If they have nothing to do directly with the motor aspect of the nervous system, they must surely have something definite to do with its other aspect, which is that of sense or feeling. We examine, therefore, the various nerves of sensation to see whether they run to, and really spring from, the basal ganglia. The nerves of sensation are old structures in animal history, and so are the basal ganglia of the brain. We might well expect to find these ganglia the seat of sensation; and there is much reason to suppose that at one time they did serve in this capacity.

But it is one of the most remarkable and significant facts of the human brain that the centers of the various senses — vision, touch, smell and so on, which are exceedingly ancient, and existed in great power for untold ages, are yet to be now found in the cerebrum — and nowhere else. These senses may have had centers when there was no cerebrum; they have centers now in animals that have no cerebrum worth mentioning. Our basal ganglia appear to correspond to such centers, but our senses have gone up higher. No doubt they still have intimate connections with the basal ganglia, and these ganglia may sometimes seem to be a sort of half-way house on the inward path of what will cause a sensation. But the reasoning centers are in the cerebrum; and if we want to know where a touch is felt, though the sense of touch is the oldest we possess, and is found in the amœba, and in every other animal, we learn that the center for the sense of touch is upon the surface of the cerebrum, which is the very latest physical triumph of organic evolution.

The body has many instances of parts which appear to be useless, but nothing is less probable than that such parts should be found in the brain, occupying any of the priceless room within the skull. There remain two facts at least of the psychical life which we have not yet allocated to any part of the brain — the intelligence and the emotions. We should certainly not expect the intelligence, so recent and rare, to use the basal ganglia, so ancient and common, and least of all when we find that the sensations, which are the data of the intelligence, have left them. But the case of the emotions is very different. Of course, they require and will receive special study, none the less because the old psychology fell far short of doing them justice. But meanwhile we may reasonably state the very high probability that the seat of the emotions in the brain is in the basal ganglia. They must have some seat in the central nervous system, and we can positively exclude all the lower parts of the brain and the spinal cord; likewise the cerebrum — a fact of great importance. Only the basal ganglia remain, and there the emotions must find their seat, unless we accept the very taking theory of William James, that the emotions have no real center or origin in the brain at all, but are only the general effect of certain disturbances of our internal organs; that we feel afraid because we feel the heart palpitating, and not that the heart palpitates because we feel afraid, for instance. If we reject



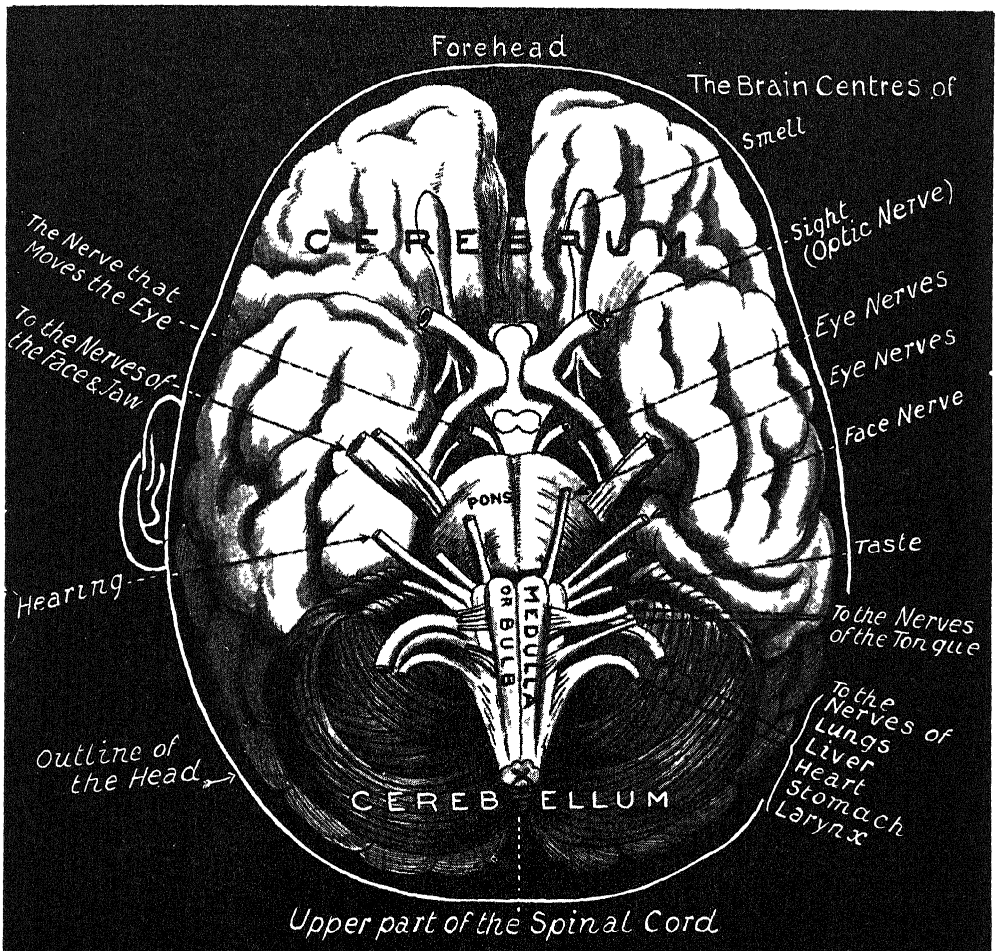
A SECTION THROUGH THE MIDDLE OF THE BRAIN

In this picture-diagram of a section through brain and spinal cord are shown the roots of the cranial nerves and the order in which they leave the brain; one only of each pair is shown

that theory, as we must while acknowledging some indebtedness to it, we cannot refuse to assign the basal ganglia of the brain to the emotions as their seat and center.

The fuller meaning of this will be realized when we come to see the strict connection between the emotions and the instincts, only perceived by psychology during the present century. We may then incline to the view that these ancient ganglia of the brain are concerned with the organization of the ancient instinctive responses of the living body, as well as with the emotions which accompany them; and we shall understand the close anatomical propinquity of the motor apparatus descending from the cerebrum to these great ganglia at the base of the brain.

Only the cerebrum and its functions remain for our study. But what an "only" is this! For the cerebrum of man is the indispensable instrument whereby he has built cities, written books, conquered the earth, and may even, at the last, become master of himself. The cerebrum is not a creator, but it is the infinite tool of man, the creator. To say

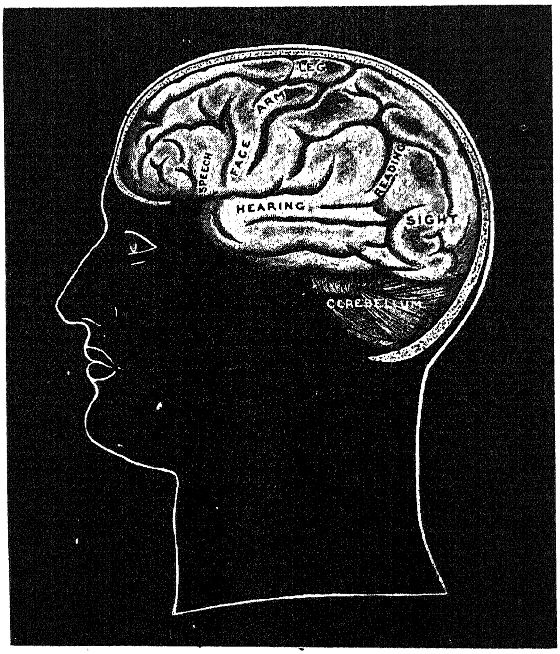


PICTURE-DIAGRAM OF THE BRAIN AS SEEN FROM BENEATH

The entire nerve of smell and the nerve-roots of the other senses and the vital organs are shown in this picture These nerves are arranged in pairs, two for each sense, and are drawn in the order in which they are attached to the cerebrum, pons and bulb The crossing of the optic nerves can be clearly seen.

that it alone remains for our study is to say that we have merely now to study man, his doings and his destiny! We shall not leave this subject; and here we must begin with a statement of the main anatomical facts.

This cerebrum is a strictly double organ, consisting of two halves, one on each side, which are connected in various ways. We observed the legitimacy of regarding the heart as a double organ, and speaking of a left heart and a right heart. No less legitimate is it to speak, as we often do for short, of the left brain and the right brain. But the proper designation of these two halves, which we see at once in any but a side view of the brain, is the *cerebral hemispheres*—the two hemispheres of the brain wherewith man has conquered the two hemispheres of the earth. Ideally, so to speak, they are symmetrical, but we find that, in the right-handed adult, the left hemisphere is always slightly the larger of the two, and conversely in left-handed persons. We shall find, also, that on critical examination of the functions of the hemispheres, this disparity is found to be far more marked, one or other being the "leading half" of the brain in everybody, and discharging exalted functions, such as speech, of which the other, the "led half", is incapable. But historically and ideally the two hemispheres are symmetrical; and this we observe directly we begin to follow the very strange and intricate pattern which they display upon their surface. They are not, however, independent. They can be brought into relation, somewhat indirectly, by means of messages sent down and up to and from the lower parts of the brain and spinal cord; they are connected by tiny strands of nerve-fibers that cross the middle line, but chiefly they are connected by a very large and dense body of nerve-fibers, so firm that it is called the *corpus callosum*, which forms a myriad-fold bridge of communication between the two sides of the cerebrum. We shall find that fibers from every part of each hemisphere run through the corpus callosum from side to side, thus intimately connecting the two hemispheres and enabling them to act as one.



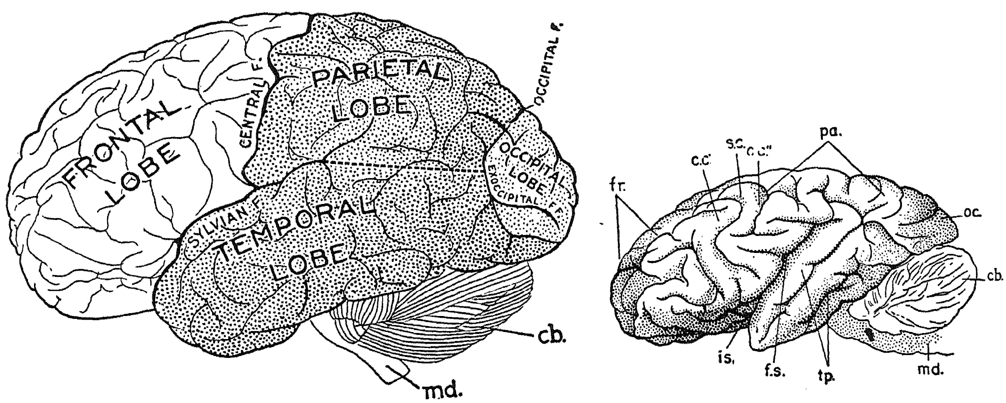
SOME CONTROL-CENTERS OF THE BRAIN
This picture-diagram of the left surface of the brain shows the portions concerned with various senses and movements of limbs. Should the portion of the brain marked "leg" be destroyed, paralysis of the right leg would result.

It is well known that we gain an advantage in seeing with both eyes. Binocular vision gives us a view a little way round an object, and we see its solidity and depth to some extent. Hence, Dr. John Brown, the famous author of "Rab and His Friends", argued long ago that there may be a difference between the kind of thinking that is performed with only one hemisphere and that which employs both sides, so that, as it were, we can think round and see round our subject better. This is at present only a suggestive speculation, and cannot be verified; nor need we necessarily assent to the view that reasoning is performed by interchange of messages between the two cerebral hemispheres by means of the corpus callosum. But it is at least certain, as we shall learn later, that the brain is very rich in association areas and association fibers, as they are called, which

connect different parts of each hemisphere with each other; and the fibers which cross from one hemisphere to the other are evidently part of the general association system that is found to be so marked a characteristic of the human brain. And unless we assume, as some have done, that the "leading half" of the brain does all the thinking and all the remembering, which is highly improbable, we must agree that congenital absence of the corpus callosum, as is found in some defective brains, must sadly interfere with thought, and that it is well to try to use both sides of the brain, rather than one only. But whether this is to be achieved by the cultivation of ambidexterity, and whether it is impossible except for those who have learned to write, and so on, with both hands, is another question which we shall not attempt to decide at present. But we see the anatomical basis for the theory of the champions of ambidexterity.

The cerebral hemispheres are covered with a triple coat of membranes, or meninges, inflammation in which, due to the microbe of tuberculosis, or others, constitutes the well-known malady called meningitis. If this occurs very early in development, and interferes with the circulation of fluid inside the central canal of the nervous system, as it may do by blocking up certain apertures, the fluid increases in bulk, and swells the brain and the head, producing hydrocephalus, or water on the brain. But though we must recognize the existence of the central canal of the nervous system, and of the "cerebro-spinal fluid" which it contains, and of the ciliated cells which line the tube, we are still uncertain as to all the functions of this fluid, and the spaces, within the cerebral hemispheres, which it fills.

Under the three meninges, or "mothers", of the brain, the *dura mater*, the *arachnoid* and the *pia mater* — "hard", "spider-like", and "tender", respectively, in the old terminology — we come to the surface of the hemispheres themselves; and a glance within shows that the disposition of the nervous elements is the same here as in the cerebellum, and the opposite of what we find, for instance, in the spinal cord. The gray matter, containing the nerve-cells, is without, and the white matter, composed of the nerve-fibers, is within. We see, further, a similar arrangement for increasing the surface to that which was employed in the cerebellum. The surface of the hemispheres is deeply grooved with a great complication of branching fissures, or *sulci*, which mark the surface out into a number of folds, convolutions, or *gyri*. The gray matter dips down into the fissures, thereby explaining their presence. If the gray matter of the average brain were to be disposed in its present thickness, upon a smooth surface, the brain, and therefore the skull, would have to be most unmanageably large.



THE SIZE AND STRUCTURE OF THE BRAIN OF MAN AND THE CHIMPANZEE COMPARED

The brain of the chimpanzee is not as long as the human brain and has only about one-third its bulk. Its frontal lobes are less developed, and the cerebrum does not extend beyond the cerebellum. *cb.* cerebellum; *c.c.'*, *c.c.''* anterior and posterior central convolutions; *fr.* frontal lobe; *f.s.* Sylvian fissure; *is.* island of Reil; *md.* medulla; *oc.* occipital lobe; *pa.* parietal lobe; *s.c.* central (Rolando's) fissure; *tp.* temporal lobe.

Number and depth of convolutions more important than bulk of brain

The brain has always steadily grown. The earliest cerebrum we know, far down in the scale of life, is perfectly smooth. Gradually the device of infolding has been adopted, to afford a larger surface in the same space. We pass upward through the vertebrate series, and find the head, the cerebrum, and the folds of the cerebrum steadily increasing. The growth of the cerebral *surface* has constantly outrun the growth of its bulk and of the skull. Thus, the fissures are always becoming deeper and more numerous, until we reach the cerebrum of man, in which the hemispheres are fissured to an unparalleled degree both in number and in depth. We may argue that the gray matter might have been made thicker, and it is thicker than it used to be, but evidently there is a limit to useful thickness, and intercommunicating areas of wide extent are preferred. That is attained by thus throwing the surface of the brain into a series of convolutions.

The number and depth of the convolutions vary very considerably in different people, and are undoubtedly related to the quality of the brain, to which they afford a far more trustworthy index than its mere bulk. This fact is, of course, fatal to the pretensions of "phrenology", while it offers the possibility of a new phrenology to which there may be no end. The *extent of surface* gives us, substantially, the *real* size of the brain. Just as comparative and evolutionary study suggests, the fissures are most numerous and deepest in the brains of the higher races, and in individuals of the highest cerebral powers. And agencies, toxic and other, which practically reduce the extent of the brain surface, by destroying the cells which compose it, do directly reduce the mental capacities, as also often the moral capacities, of the affected individual.

The white core of a cerebral hemisphere constitutes by far the greater part of its bulk. The fibers run in all directions, and must be traced, to some extent, when we try to unravel the working of the brain. Meanwhile, we reflect that, for every one of these fibers, there must somewhere be a nerve-cell which nourishes it and employs it, and from which it sprang. The nerve-cells, then, are the essential part of the hemisphere, and we find them exclusively in the gray matter of the surface In the white core none are to be found. Other cells there are: those which constitute the walls of blood-vessels and lymph-vessels, and also a peculiar type of cell, with many branching processes, which are called *neuroglia*, or "nerve-glue", cells. They are the connective tissue, the "glue", of this part of the body, and are peculiar to it. Everywhere they fill in gaps and hold things together. They look very unlike ordinary connective tissue-cells, and rather like nerve-cells, as if aping the tissue they are made to serve.

But they are really only humble connective tissue-cells, nevertheless, but formed from the ectoderm, or outer layer, of the embryo, and they retain the primitive power of division and multiplication which nerve-cells have utterly lost. Thus, when nerve-cells are destroyed, by poisons or otherwise, neuroglia-cells take their place; and the degenerate brain, perhaps bigger than ever, consists of connective tissue which cannot think, just as the degenerate heart, also larger than ever, consists of connective tissue which cannot contract. Further, we observe that the various tumors of the brain never consist of nerve-cells, which are incapable of forming tumors, innocent or malignant, but consist of cells derived from the neuroglia or the meninges, or some other humble tissue.

And so we pass to the last anatomical unit of the cerebrum, the nerve-cell, as we find it in its millions in the mantle of gray matter that covers the hemispheres and lines their fissures. If we make a section through a hemisphere, at any point, the contrast between the gray surface and the white interior is very obvious. The gray matter is the "bark of the cerebrum", or *cortex cerebri*. It is the essential home of man, his organ of organs, instrument of instruments, becoming more and more the master of all the nerve-cells beneath it, and through them of the external world.

DRUGS: THEIR USES AND ABUSES

The Decadence of Drugging
and the Triumph of the Drug

TEACHINGS OF SUPERSTITION AND SCIENCE

THE reader who thinks that the whole of health is bound up with what one swallows need not fear that we have forgotten diet and its problems, or are going to deal with them perfunctorily. But first we must deal with the question of drug-taking, and note not only its practical importance at the present day, but also the verdict of modern science upon the use of drugs in health and in disease.

In these days when the sulfa drugs and the antibiotics are so popular, there is a tendency to think of drugs as cure-alls. Instead of relying on proper dieting or sensible exercises, we are apt to ask the druggist if he can give us some pills for whatever ails us. Wise people in every age have protested strongly against this practice. More than half a century ago, Dr. Oliver Wendell Holmes, who was a wise medical observer as well as a humane and illustrious thinker, expressed in characteristic fashion the conclusion to which he had come: "I firmly believe that if the whole *materia medica* could be sunk to the bottom of the sea it would be all the better for mankind and all the worse for the sea." And, more recently, Sir William Osler declared that he is the best doctor who best knows the worthlessness of drugs.

There may be some among our readers who may be inclined to ask what the modern doctor is good for, if he fails to prescribe some medicine or other for us. If such a reader were to consult such a doctor, and receive no medicine for his pains, there would be trouble. In fact, the doctor *must* give medicines, for his patients will all leave him unless he does so. If the case is one where available drugs can be of service, well and good; but, if not, the doctor must prepare something or other, preferably with a substantial flavor and smell and color, in order to please the patient.

Very often the drug does good, and is justified, even though any other harmless drug would have done just the same good. The action is through the patient's mind upon the patient's body, a fact of which the patient has no idea; but a faith-cure is none the less a cure, and a much better thing than no cure at all. The sense of mystic comfort which, for most people, attaches to the taking of medicine is beyond question; and it is a fact which the wise practitioner cannot ignore.

The importance of this subject as regards individual conduct also has never been greater than it is today, as every doctor knows. The horrible and offensive drugs used in former days were at least difficult to obtain, and had to fight against the objections offered by the patient's nose and palate. But today manufacturers vie in the effort to turn out drug preparations of the most attractive and tasteless kind, scarcely less tempting than candy; indeed one can now obtain all manner of potent drugs actually inclosed in chocolate and bonbons of various kinds. Hence the universally admitted fact that there was never before so much self-drugging as there is among civilized communities at the present. The drugs simply did not exist, or were not to be had, or cost gigantic sums, in former days.

How drugging arose in the days of medical ignorance

Drugging dates from days when nothing was known about the body, or about disease, or about drugs. That in itself ought to be reason enough for distrusting the practice as a whole; but a far more cogent reason than the ignorance of the past, which invented and practised drugging, is the knowledge of the present, which has studied the body and has ascertained the causes of most forms of disease. Voltaire was fully entitled to his celebrated remark about the doctor of his day — that he poured drugs of which he knew little into a body of which he knew less. The scientific study of drugs was not even conceived of in those days; there was nothing fit to call physiology; and as for disease, it was an utter mystery. The prescribing of drugs, therefore, was bound to be a hit-or-miss affair. The doctor used pompous and learned phrases in his prescriptions, but too often these phrases merely cloaked his ignorance.

The causes of disease were unknown. Thus here was to be seen an ill man who suffered from pain and fever. In the absence of any knowledge of a cause underlying these symptoms — for that is all they are — the symptoms *were* the disease. The body was misbehaving itself in the form of pain and fever. To remove or smudge over these symptoms therefore ranked as curing the disease — until the patient died.

The confounding of the relief of symptoms with the cure of disease

But while these symptoms, wrongly and shallowly described as diseases, were to be met in the sick room, the fields and the woods provided certain plants the leaves or juice or roots of which could also cause remarkable phenomena in one who swallowed them, and such drugs could accordingly be pitted against the symptoms of disease in order to neutralize them, which was called curing the disease, and which is even today the greater part of so-called medical practice. Thus the dried juice of the poppy capsule relieved pain and sleeplessness, which are among the most distressing symptoms of illness, though opium never cured anybody of anything yet; and the leaves of the foxglove would slow down an unduly rapid pulse, though foxglove, or digitalis, valuable drug as it is, never yet cured a diseased heart. These are typical and long-standing instances of vegetable therapeutics — the most ancient form of medical practice in the world, now reduced to the smallest proportions on record in the practice of the leaders of medicine.

How plants strive to repel their own enemies — not man's

There is no good reason, let alone any inherent necessity, why the active medicinal substances found in the vegetable world should serve ailing man. The probabilities are all the other way. Most of these medicinal substances, found in and made by plants, appear to be either poisonous by-products of the plant's own life, which it is in process of destroying, or else poisonous substances which it has produced to protect itself from the animal world. Thus the delicious volatile oils which furnish the finest odors are probably produced by the plant in order to warn off objectionable insects, or to destroy them if they approach; and a nauseating leaf does not constitute a thoughtful vegetable anticipation of the occasional emetic needs of man, but a means of insuring that the animal which seeks to make a meal from such a leaf shall studiously permit the tobacco plant, let us say, to grow in peace for the future.

In point of fact, the vegetable world has been ransacked, for ages, in all parts of the world, and everything, or nearly everything, has been tried for the cure of disease. Weighed and found wanting is the almost universal verdict. A mere modicum of drugs remain that have useful actions of one kind or another. Most of them are useful, not on account of anything they do to the human body, but because the very antiseptic substances which the plant uses to protect itself against microbes may be employed by man to protect him against similar microbes.

Quinine, a vegetable medicine

Quinine is one of the best-known of these vegetable products that are used to kill microbes. Quinine is an alkaloid, which can be derived from the bark of the cinchona tree; it is poisonous to the microscopic and infinitely numerous parasites that cause malaria. When quinine is administered by the mouth or in any other way, it soon enters the blood stream and generally kills the malarial parasites, whether these are free in the blood plasma or enclosed within the corpuscles of the blood. For many years the quinine produced from cinchona bark was the supreme remedy for malaria.

Within the past generation, its supremacy has been challenged. In 1944, two twenty-seven-year-old Harvard chemists, R. Woodward and William E. Doering, succeeded in making quinine synthetically, thus culminating a hundred years of efforts by scientists to produce artificially what hitherto had been produced only from cinchona bark. In recent years, also, two drugs which are entirely different chemically from quinine have proved to be effective in treating malaria. The trade names of these drugs are Atabrine and Plasmochin.

The antibiotics are valuable drugs that are derived from plants

In the forties of the present century, a new series of medicines derived from plants came to the fore; these are the bacteria-killing preparations known as antibiotics. They are made from substances produced by fungi and bacteria, which are both members of the vegetable kingdom. Among the best-known of the antibiotics are penicillin, aureomycin and terramycin, derived from molds, and streptomycin, derived from a bacterium that grows in the soil. They have proved their worth in the treatment of a wide variety of ailments, such as infections, pneumonia and blood poisoning.

Yet, in spite of the remarkable success of these drugs that have been derived from plants, the fact remains that a great many vegetable substances have proved ineffective as a cure for human ailments or else have been positively harmful.

The lost reputation of mineral medicines when tested by experiment

In the mineral world we find a parallel state of things. Iron, arsenic, mercury, sulphur, to choose notable examples, certainly have their uses, and doubtless always will have. Iron in certain forms of anæmia, mercury in syphilis, sulphur in many parasitic diseases of the skin, are not to be denied the title of cures. But on the whole the drugs derived from the mineral kingdom are in a state of decadence in modern scientific medicine. An excellent illustration of this is furnished by the drug antimony with its various medicinal preparations, which were popular for so long. Like all other drugs, antimony has had to face the tests of modern science, and it has been found wanting. It depresses the essential functions of the body, beginning with the heart, and is probably worthless as medicine.

Pharmacology is the name given to the science which has changed the face of medical practice in such respects. Its province is the action of all imaginable drugs upon the *healthy* body of man and animals (for there is all the need of veterinary medicine to meet as well). Formerly the action of drugs was only inferred from what appeared to happen in disease. Practically nothing could be so learned, and most of the positive conclusions reached under such hopeless conditions were wrong. Thus, the great heart-stimulant foxglove, or digitalis, was introduced and used for many years as a heart-sedative, because it slowed the pulse in the supposed over-action of fever. All this was wrong. The heart in fever is not over-acting, but it is poisoned, and is beating too fast because it cannot beat strongly enough; and the action of digitalis is to strengthen the beats, and therefore reduce the rate of beating that was formerly necessary. Similarly, it is pharmacology that has reversed all the popular and professional opinions about alcohol, proving that the supposed stimulant is a sedative, just as it proved that the supposed sedative digitalis is a stimulant.

On the whole, the result of pharmacology has been to discredit the overwhelming majority of all the drugs used in the past, and to reduce the number of them that are worthy of use to a mere handful. These negative, destructive results of modern knowledge have been especially insisted upon so far in this chapter; but the reader is by no means to suppose that there have been no constructive ones.

For the reader will observe that, besides the vegetable and mineral kingdoms, there is a third, to which we have not even alluded as yet. Might not the animal kingdom furnish chemical resources well suited to serve the needs of such another animal as the body of man? Here is quite a new idea — only that it is also one of the oldest in the history of the medical art. The answer to this question must now engage our attention, and will that of medical science for many decades to come.

The new source of drugs

From the oldest times until the rise of modern medical science, drugs or substances of animal origin had been very largely used by the medical profession. According to the old doctrine of "signatures", one wandered about a field or shrubbery, picking out a leaf of some quaint shape more or less suggesting an animal organ, and then used decoctions of that leaf for supposed maladies of that organ If that was regarded as sound reasoning, obviously there was something to be said for actually giving doses of the liver of an animal to a human patient whose liver was supposed to be out of order. We must remember, also, the old psychological theories, familiar to every reader of the classics, according to which certain facts of emotion and desire had their seat in certain bodily organs, such as the liver, the kidneys, the "bowels of compassion", and so on. Here, again, was an argument for administering drugs of animal origin to ill people; and if any further motive was needed, there was all the influence of classical augury, in which the entrails of animals were consulted for decisions as to, say, naval engagements and personal matters as well.

All these notions are now simply part of the history of ignorance; and the time came when doctors began to abandon the use of animal drugs, on account of their palpable failure And if we marvel at their offensiveness, we must remember that disease was regarded as due to possession by an evil spirit, and horrible drugs administered in order to disgust it with its abode, and effect its departure. When the development of modern science, after the revival of learning, began to discredit all such notions, and when the advance of chemistry gave physicians a variety of new drugs derived from the mineral and the vegetable kingdoms, these horrible animal messes were largely abandoned

Yet, if the reader will remember the scientific argument against the probability that vegetable drugs will cure our diseases — namely, that the chemistry of the plant is irrelevant to the chemical processes of man — he will also see that the chemistry of the bodies of animals must surely be very closely allied in many ways to the chemistry of the human body. We should reasonably expect that, if only the resources of the body of some animal could actually be applied to ourselves, they might, for instance, just contrive to supply a deficiency in our own chemical resources. And that is exactly what has been found.

Consider, for instance, the malady of development which is called cretinism, and also the disease of adult life which is called myxœdema. These diseases and some others are now all included under the excellent general term of athyrea (where the *a* is negative, as in atrophy or apathy), in order to indicate that they are due to deficiency in the action of the thyroid gland in the neck. Once we learn, according to this theory, that certain kinds of imbecility, hitherto absolutely hopeless, are due to defective production of certain chemical bodies by the thyroid gland of the patient, the ancient principles of animal therapeutics, so long dead, spring to life again. We kill a sheep and remove its thyroid gland, which we thereupon administer to the cretin child, and the imbecile becomes educable, intelligent, human. The drug is relevant.

The triumph of the antitoxin treatment in diphtheria, and what it suggests

That was one of the two great therapeutic triumphs of the last decade of the nineteenth century. The other was the antitoxin treatment of diphtheria; and as in the first instance man applied in his extremity to the thyroid gland of the sheep, so here he applies to the blood of the horse. If the poisonous juices, or toxins, of the microbe of diphtheria be brought into relation with the tissues of the horse, those tissues — perhaps the white blood-cells, perhaps something else — produce an antitoxin, which neutralizes the poison; and the production of the antitoxin far exceeds the need, so that in a short time not only is all the toxin in the horse's blood neutralized, but there is also present a great excess of free antitoxin. A child is in the grip of diphtheria, which is clutching at its throat and about to choke it. The child's body is behaving exactly like that of the horse, and producing an antitoxin, but not quickly nor abundantly enough. Let us now reinforce the child's insufficient antitoxin with some of the surplus in the horse's blood. The result is almost instantaneous. The whole meaning and significance of diphtheria have been transformed. The death-rate has been reduced *in exact proportion to the stage in the case when the antitoxin is applied;* no child treated on the first day ever dies, scarcely any treated on the second, and so on. The drug is relevant.

The downfall of drugging and the triumph of really relevant drugs

As long as the maladies due to thyroid insufficiency, or "athyrea", were not understood, hundreds of drugs would be used to combat them, and every new one would be welcomed for its possibilities. Reduce all these maladies and their quite innumerable symptoms to thyroid insufficiency, and instantly you sweep away a shopful of irrelevancies with a single relevant substance.

Let us be clear where we are, and what are the conclusions from our arguments.

Thyroid extract is, of course, a drug. So is diphtheria antitoxin. Nothing could be more untrue than the statement that the most competent physicians use no drugs nowadays or have no faith in them. But it is true that, where their predecessors used scores of drugs, such physicians will scarcely employ more than a dozen, of which, perhaps, neither their predecessors nor the present public have even heard. Again, antiseptic surgery is the triumph of a drug — carbolic acid — but, again, a relevant drug, deliberately selected for its known poisonous action upon the microbes which cause surgical inflammation. Our phrases, then, must be chosen with circumspection; we certainly cannot speak, as some have done, of "the decadence of the drug", but we certainly can speak of "the decadence of drugging". There is all the difference in the world. And if we include among drugs, as we must, the whole series of antiseptics and anæsthetics, together with antitoxins, vaccines and sera, and other substances of animal origin, then certainly the present age of medicine displays what may properly be called the triumph of the drug. Only it is a triumph of this kind — that those who best understand and most profit by it are the most sparing and fastidious and infrequent in their recourse to it.

The body only adapted for the consumption of food — not of drug poisons

The future of drugs, in their scientific employment, demands our attention, and then we shall be fully prepared for the practical moral. No modern physician of the first rank now writes the sort of shotgun prescription with which so many of our forefathers were peppered and slain. We recognize now that any drug must be regarded as a poison until the contrary is proved — and the contrary never is proved. What, indeed, happens is that successive inquiries condemn as poisons many substances which we had supposed to be innocuous, like the boric acid which is added to milk and cream and butter, or was until recently, and the saccharin which people take instead of sugar.

The body is not adapted for the chronic consumption of anything but *foods*. We have learned that even invaluable drugs like quinine are essentially poisons. Metchnikoff insisted upon the fact that this drug tends to paralyze the white cells of the blood; and every doctor knows how liable it is to cause toxic symptoms associated with the sense of hearing. Fortunately, it is much *more* poisonous to the parasite of malaria than it is to us.

The danger that lies in drugs that are really useful

So far as drugs for producing particular effects upon the body are concerned, we have yet to find those which are without risk or danger. The ideal hypnotic, the ideal antiseptic, the ideal anæsthetic, do not yet exist. Those with which the public experiments upon itself so freely do not answer to the description. The antiseptic which is so general in its action as to kill microbes in general is also, and therefore, so general in its action as to kill living cells in general. The public may be persuaded to swallow boasted antiseptics, in consumption and the like, so as to kill the microbes, just as the medical profession ordered antiseptics like creosote for consumption twenty-five years ago. But we now know that, if the general antiseptic is efficient, it is also deadly to the patient's body; and if it is indeed harmless to the patient, it is harmless to his enemies. The future, in this case, lies with the special antiseptics so made as to kill or neutralize special parasites or special poisons, and without any other action. The diphtheria antitoxin is a case in point.

As regards anæsthetics, the public must not suppose that we yet possess anything which is safe for the amateur to employ. People may take chloroform or ether, in small doses, whether by inhalation or by the mouth, for long periods, just as they take the third anæsthetic, alcohol, which is so often combined with them in the "A. C. E." mixture, but doctors know that the effect upon the brain is very serious indeed, and that such treatment is a remedy worth having for no disease or symptom whatever.

There is no ideal anæsthetic or ideal anodyne. We seek in vain for a drug which will relieve pain, and do no harm. Medicine and chemistry know nothing of such a drug, though they know many that may be used with caution, on special occasions, for short periods. But the public assumes that the ideal anodyne, unknown to science, really exists; that it is possible, for a few cents, under any fancy name, to purchase a drug which is so powerful that it will arrest the functioning of an irritated nerve-cell, and yet so innocent that it will do that nerve-cell no harm. The belief is absurd, but thousands of people act upon it every day.

The ideal hypnotic not yet found, and not one fit for the public to help itself to

The case is exactly the same as regards the ideal hypnotic. It does not exist. No doubt German chemistry has done great things in this direction within the last three decades; and in the absence of opium the practitioner is no longer left with chloral alone as a substitute. What we need, however, is a hypnotic which produces the hypnotic effect, and no other, and never loses it. We may yet discover such an hypnotic in the animal kingdom, but meanwhile the verdict, here also, is that there is nothing which is fit for the public to help itself to without medical supervision.

So far as the actual cure of disease is concerned, the future belongs to the animal kingdom, so long neglected; and if we believe in the *vis medicatrix Naturæ*, we can hardly be surprised. The healing power of nature is effected, in the animal body, by animal substances; the thyroid gland will cure or prevent cretinism, the white cells of the blood produce substances that destroy microbes, and so on.

The new medical science simply takes the hint from nature, and applies with intelligence the substances with which she has been preventing and curing disease ever since pain and death first came into the world. This is the proper reply to the unfortunate cranks who inveigh against, say, the antitoxin treatment of diphtheria as unnatural.

The only safe course — not to take any kind of drug without advice

The object of all the foregoing, for the lay reader, has been to justify up to the hilt the practical conclusions at which we are bound to arrive in the interests of hygiene. From the nature of the case, we now see, the drugs which so many of us consume are incapable of curing our disorders, and can, at most, do no more than mask them. Let the reader be specifically warned against all drugs that contain opium, morphine, chloroform, ether or alcohol, even openly, and in small quantities; against the most accursed drug, called cocaine, which is now destroying so many lives in the United States in the larger cities especially; against chloral, chloralamide, trional, tetronal, sulphonal, paraldehyde, veronal and all other hypnotics ending in *al*, or any other terminals; against antipyrin or phenazonum, antifebrin or acetanilid, phenacetin, exalgin, antikamnia, chlorodyne, and their congeners, one and all. The results of taking these things, none of which is a *cure* for any known disease, are only too often horrible in the extreme; and their nature is such that the only safe course is not to begin their use. They attack the centers of self-control or inhibition, and there is little hope or help when these are captured.

The evil of handing prescriptions from patient to patient

Many of these drugs have their uses on occasion; and if they be freely given it is possible for the doctor to gain the temporary gratitude of his patient by their employment, but the risk of prescribing them, except in the most rigidly limited way, is one from which the conscientious practitioner must always shrink. Though they are sometimes useful, so are arsenic and prussic acid, but it is really more necessary that their employment should be limited and under responsible control than in the case of these two notorious poisons. Indeed these, and many besides, should be labeled poisons, which they really are, and should be so prescribed.

It ought also to be quite impossible to repeat such prescriptions without the doctor's order, and absolutely out of the question that the prescription should be handed from one patient to another, for those who have no knowledge at all cannot judge whether the prescription which suits one patient is suitable, or even safe, for another. As for drug habits which have been started in this way, their name is legion.

Curative drugs of the body's own making

So much for those recognized and official drugs, of which the dangers, unfortunately, are so little recognized. And now let us return to the general conclusion which has been asserting itself all along: that the drugs of the future will be obtained from animal sources. We have quoted two great illustrations, and the reader must already have observed that his own body is manufacturing "thyroid extract", that marvelous drug, for itself all the time, otherwise he would either be a hopeless fool, by no means reading these lines, or, if he were producing no thyroid secretion at all, he would almost certainly be dead. Similarly, though his body is not producing diphtheria antitoxin at the moment, that is merely because, in all probability, he is not just now being attacked by the diphtheria bacillus — or it would be doing so. The meaning of all this is clear. If we find that, for drugs that are really worth talking about, we have to abandon the vegetable and mineral kingdoms, and search the animal body, it is clear that the *vis medicatrix Naturæ*, long worshiped by the wisest of the ancients, has taken bodily form at last.

How the healthy body makes drugs to keep its own health

Modern science finds this mystic power incarnate in the living body, and its instruments can be isolated, handled, weighed and tasted. In a word, the really curative drugs are of the body's own making, nor, with a rare exception or two, are they to be purchased at almost any pharmacy. We are only beginning to isolate these drugs, and little enough is known about them.

But at least the modern physiologist knows that the greater part of any serious discussion of personal hygiene, such as this present one, is really concerned with the production and employment of these curative, *and preventive*, medicines in and by the healthy body. The writer of the treatise may not know it, nor may his readers. Yet that is what they are really discussing and aiming at all the time. He tells them to breathe open air, because experience shows its value; but his successors, a generation hence, may be able to isolate from the body the exact chemical substance which is best produced by it under the influence of open air, and which antagonizes disease — say, by making the body uninhabitable by any given microbe. Thus the reader who now attends to the advice already given regarding open air, or on many other points, is favoring beyond a doubt the conditions under which the protective and curative substances are manufactured, dispensed and administered in and by his own body, which is far and away the wisest and most accomplished of manufacturing chemists, and incomparably superior to any doctor in the diagnosis of its diseases and their treatment.

The natural antiseptics which are produced by the body to kill its enemies

All this is so important and so radical in our modern conceptions of hygiene, and so entirely condemnatory of the practice of self-drugging, from which we desire to exclude every reader of THE BOOK OF POPULAR SCIENCE, that a few illustrations must be cited. They range from trifles to the most mortal diseases. Thus, the healthy nose secretes an antiseptic mucus, which largely kills objectionable microbes, such as those which produce a common cold, influenza or pneumonia. The healthy blood contains antiseptic substances which must frequently be called upon to destroy the microbes of consumption. We have evidence that the greater number of all people have been attacked by consumption during the course of their lives, and have rapidly recovered, probably without any idea of what had happened. The recovery was due to the body's own antiseptics. If the doctor tries to add antiseptics to the body for this purpose, he always fails; and on the day on which the researchers isolate, in the body, the substance which it makes for its own protection against the tubercle microbe, and succeed in giving it to patients without destroying its powers *en route*, on that day all cases of consumption will be curable and will be cured.

How the stomach protects itself against infection from living organisms

The healthy stomach — but observe that we speak always of the *healthy* nose, the *healthy* blood, the *healthy* stomach — produces a "mineral acid" called hydrochloric. It is the acid constituent of common salt, for instance, and is really a most strange and surprising thing to find produced in the living body. It is of value in digestion, but it is far from being indispensable for digestion and the kind of digestion which it performs, or, rather, facilitates, is better performed in the bowel with the aid of a powerful alkali. Yet this acid is always formed in large quantities by the healthy stomach, which is richly provided with millions of living cells that exist solely for this purpose. Now, hydrochloric acid is an antiseptic, and has long been known to kill various yeasts and other fungi, which may be swallowed in the food, and which multiply in the stomach, causing tragic dyspepsia if the hydrochloric acid is not properly formed. It is the natural antiseptic of the body, or one of them, for there may well be thousands; and it daily saves us from all manner of infections due to the living organisms that we swallow in all uncooked or imperfectly cooked food.

Spontaneous cures always going on in our bodies without our knowledge

To these instances add the thyroid secretion, which is daily curing or preventing — either word will do — in each of us such diseases as cretinism and myxœdema; the pituitary secretion, which, by its right quantity and quality, is preventing acromegaly; the secretion of the adrenal

glands, which is preventing Addison's disease; the invaluable internal secretions of the racial glands, without which we should not be ourselves. And now authorities on cancer are declaring that probably in very many people malignant growths are started, and then suppressed, by the resources of the body without anyone knowing anything about it; that the healthy body is constantly producing substances which are antiseptic, so to speak, to the cancer cells which would otherwise develop in it, and that the "spontaneous cure" which is sometimes seen in cancer, and is probably far commoner than we know, is due also to the sudden determination of the body to rid itself of the invader. It is along these lines, doubtless, that the certain and constant cure of cancer will ultimately be achieved. Nothing more need be said on that subject now. The point is that, in the whole range of disease represented by the contrast between a cold and a cancer, the same principles are illustrated. It is by its own chemical products, made on purpose, inimitable in fitness, safety, variety, delicacy, certainty of administration, infallibility of diagnosis, that the body keeps itself well, controls insurrection, checks waste, neutralizes poisons, destroys invaders and goes boldly forward, never doubting.

Folly of drenching the body with alien drugs that probably only do harm

That is the conclusion of modern knowledge. That is the fact which modern science seeks to elucidate and modern practice to apply; and in the light of that great conclusion, so new and yet so old, we must approach and censure, almost without reserve, the ever-increasing folly which drenches this house of life, so powerful and delicate, so wise and so heedful, with alien drugs which can rarely do it anything but harm. No doubt a new era is approaching. But our say must be said, if we are to carry out a leading principle of this section, which is to warn the reader against all manner of poisons; for alien drugs in general, like the gases of foul air and the products of over-eating, fall within the category.

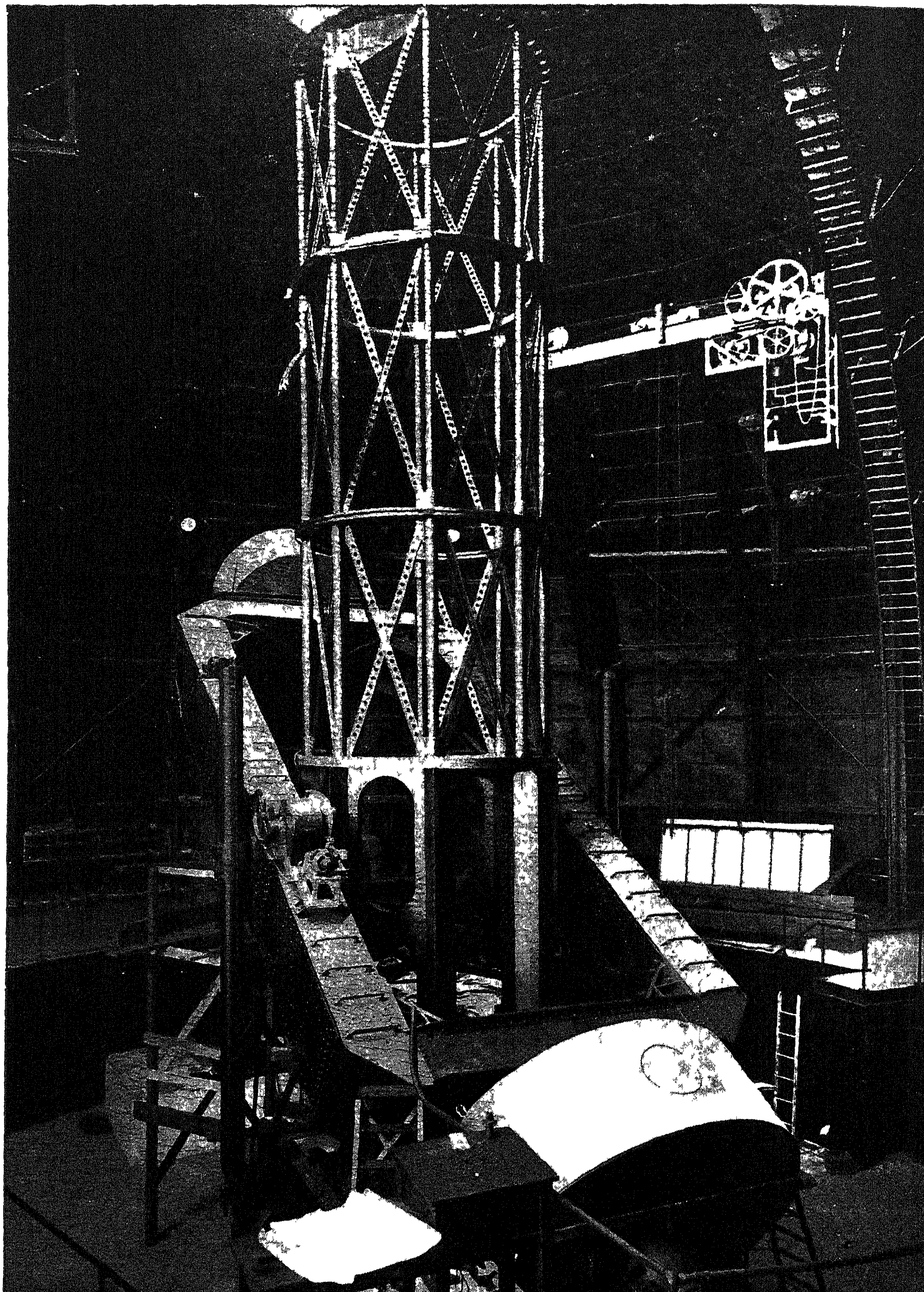
How people who drug themselves pay ten times the cost of the drugs they use

Patent medicines are largely consumed by people of small income, and therefore the question of their cost is important. That is the first objection to a very large number of them, of which the only active principle is aloes, and which may often be very useful indeed. The great malady of civilized life among the sedentary is constipation. We shall see, in due course, what are its causes and the proper ways of dealing with it — ways simple and pleasant and certain. But at present the public is not instructed in these matters. The children do not learn about them at school, and, no doubt, the present work involves the most extended and comprehensive instruction of the public in these scientific matters of personal moment that has ever been achieved hitherto. Such being the state of the popular mind, and such being the demand of the sedentary bowel, of course there has sprung up a great supply of aperient medicines, very rarely departing far from aloes as their staple. This is an excellent drug, and every doctor employs it. But there are two objections to the popular use of it in this way. In the first place, aloes is a very cheap drug, and there is no good reason why people who can afford no luxuries should pay ten or fifty times the fair price for a combination of, say, aloes, ginger and sugar. That is clear enough.

Drugs that may be used occasionally, but become harmful if used habitually

But a graver objection to self-drugging, even with such inherently harmless substances as aloes, and even for states of the body which require some such attention, is that every drug may be administered in a right way or in a host of wrong ways. Every textbook on therapeutics points out that aloes is an unsuitable drug to use habitually in chronic constipation. Its action is not tonic upon the flabby bowel, and it leaves the bowel with a greater tendency to constipation than ever. Therefore the wise doctor employs it only for special and exceptional purposes.

THE HOOKER TELESCOPE



THE 100-INCH REFLECTOR AT MT. WILSON OBSERVATORY

CONQUERING THE SUN

The Investigation of the Central Force Which Sends Energy Nearly a Hundred Million Miles to the Earth

A TELESCOPE ON A CALIFORNIA MOUNTAIN TOP

THE greatest problem in astronomy is the evolution of the stars. The star nearest to us is the sun, on which depend the lives of all living things.

Nothing that goes on in the sun is unimportant to us The cost and the quantity of all our food supplies are directly governed by the amount of sunlight and by the amount of electric force which radiate from the fiery furnace in the heavens, round which our planet spins. If it can be clearly established that there is a close connection between changes in our weather and the regular variations in the shell of the sun, then we may at last be able to foresee the recurrence of bad seasons, and make provision against them.

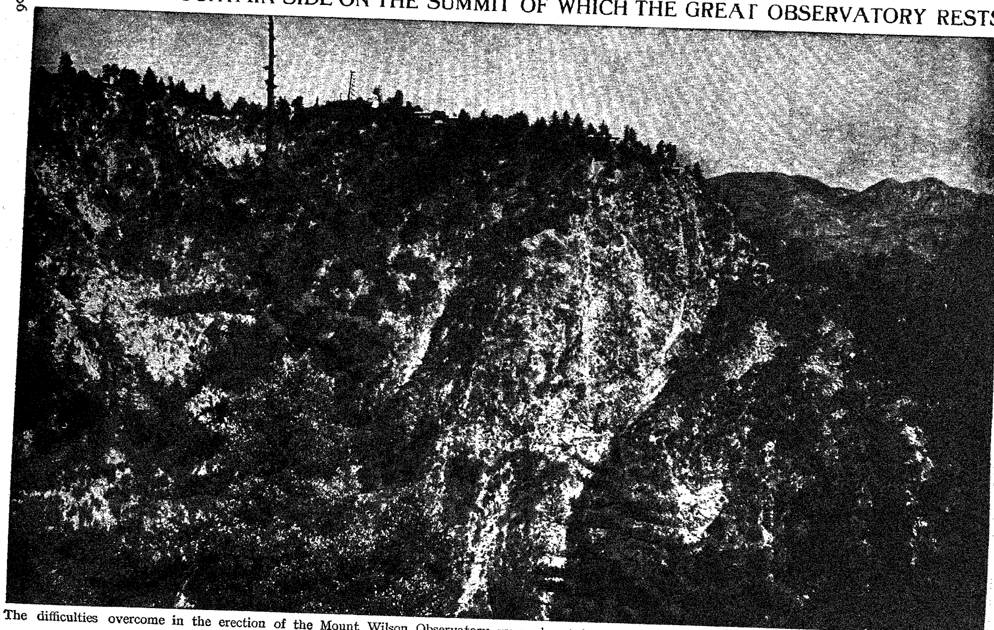
Extraordinary advances have been made of late in our knowledge of the sun; and it is beginning to look as though man, the conqueror of the earth, will eventually obtain sufficient knowledge of the flaming center of the solar system to make a more scientific use of its terrific forces. At present we lack the power, born of science, which would enable us to foresee what is about to happen. Nearly 93,000,000 miles away from us glows the great sun, in the heat and light of which we live with scarcely any more foreseeing knowledge of it than a kitten has of the kitchen stove by which it basks. It is true that we are aware of the recurrence of the four seasons, but so are the birds that migrate southward to avoid the rigor of winter. Is there anything now going on in the sun that will produce on the earth next summer disastrous weather, poor crops and scarcity of food? To this question no one is yet able to give a positive answer.

Yet much is now being done in the great solar observatories scattered about the earth to enable the man of science of the future to forecast the play of some of the vast forces in the sun. Sometimes an apparently unrelated experiment in electricity, conducted in the underground chambers of a laboratory, helps us to understand what is taking place in the star round which our life centers. For there are strange and mighty manifestations of electric energy in the sun, constituting problems that we must solve before we are able to grasp the knowledge we so ardently desire.

Owing to the generosity of a number of rich men in the United States, the best means of studying the sun are now possessed by American astronomers. Our instruments of research are the finest in the world. We have many telescopes of greater power and precision than any in actual use in Europe; and we have applied our native talent for invention in devising new and wonderful apparatus for ascertaining the actual composition of the sun.

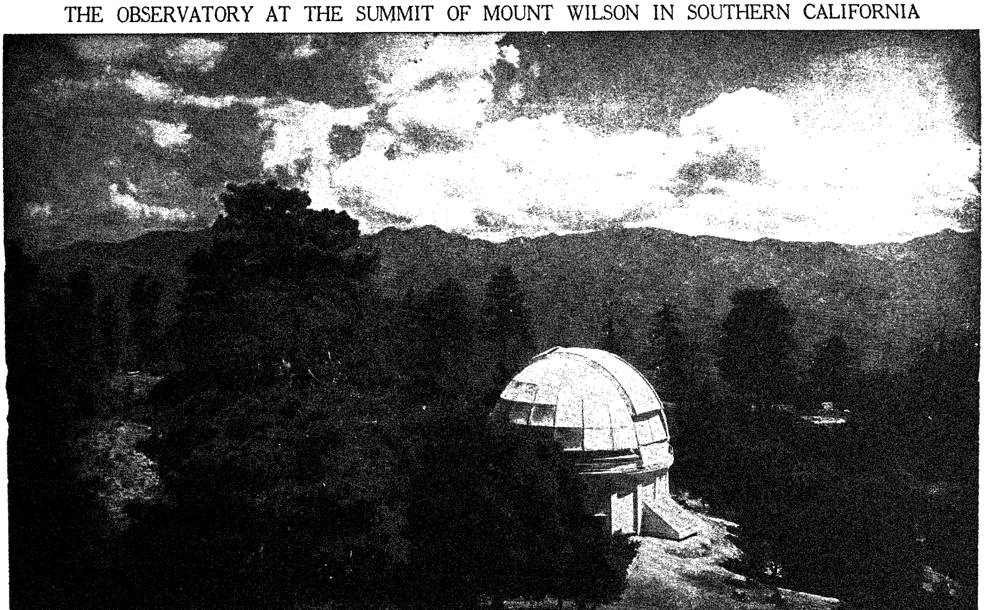
One of the most famous of all the American observatories is that on Mount Wilson, near Los Angeles, California. The first work and planning for this great observatory was carried out in 1904 and 1905, largely by the eminent astronomer, Dr. George Ellery Hale. The largest telescope in the world, up to the time of the completion of the 200-inch instrument for Mount Palomar near San Diego, was the 100-inch reflecting telescope at Mount Wilson. This great instrument was completed in the year 1917.

THE SHEER MOUNTAIN SIDE ON THE SUMMIT OF WHICH THE GREAT OBSERVATORY RESTS



The difficulties overcome in the erection of the Mount Wilson Observatory were almost inconceivable, all the building materials and instruments being hauled up the side of the mountain.

THE OBSERVATORY AT THE SUMMIT OF MOUNT WILSON IN SOUTHERN CALIFORNIA



This steel building stands nearly 6000 feet above sea-level. The great dome, 58 feet in diameter, contains the 60-inch mirror-telescope, the glass disc of which weighs one ton. To keep the temperature of the building constant the walls are of steel, two feet apart.

For some time, the astronomers of the Carnegie Institution of Washington searched the world for the site of an observatory which should command a clearer view of the sun than any then in existence. They went as far as Australia; they glanced at Arizona; and at last, in 1904, they chose a mountain in Southern California. Many things had to be avoided. Bare rocks and earth would absorb the heat of the sun and give out this heat, thus disturbing the air and interfering with telescopic work; high-lying clouds would continually obscure the view; and high winds and bad weather would be generally disastrous to the series of solar observations that was contemplated.

By placing a telescope on a height a mile or two above the sea, we do not, of course, get appreciably nearer to the sun and stars. Light travels at a speed of 186,000 miles a second; it takes about a second and a quarter to come to us from the moon, and about eight minutes to reach us from the sun. To pass, however, across the distance which separates us from the nearest star outside our solar system, it takes about four and a quarter years. Light from the most distant stars in the Milky Way Galaxy in which the sun has its place takes about 80,000 years to reach us. Standing on a mountain does as little as standing on a mole-heap to bring the stars nearer to our vision.

How the earth's atmosphere shuts us in from a trustworthy study of the sun

The trouble is the thick atmosphere that envelops our earth. We live at the bottom of a sea of air, which prevents us from viewing clearly everything beyond it. It is air that makes the stars seem to twinkle, though they are really steadily flaming suns; it is the air which absorbs many of the shorter light-waves, and gives us a wrong impression of the heavenly bodies. Especially is this so where modern photographic methods of study are employed. It is the shorter waves of light — blue, violet, ultra-violet — which affect a photographic plate, but the air stops these more than it does the long, red waves of light.

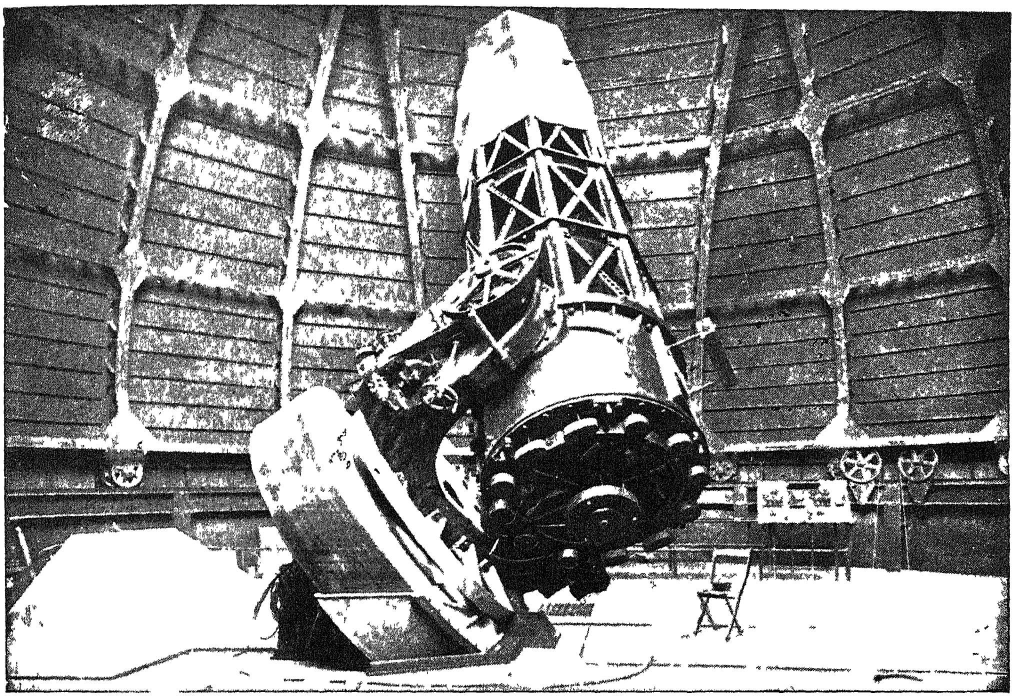
For these reasons, altitude is of great importance to astronomers. A mountain lifts them above the thick layers of air, and enables them to make more delicate and exact observations. Mount Wilson, which was selected as the site for an observatory using the largest and most powerful telescopes in the world, is one of the many heights that form the southern boundary of the Sierra Madre Range Standing at a distance of thirty miles from the Pacific Ocean, it rises nearly 6000 feet above the green ranches and thriving towns of Southern California. The view southward reaches to Mexico, and seaward it extends to islands in the Pacific one hundred miles distant. To the north, bare vast ranges of rugged heights shut out the Mojave Desert, but near at hand the high lands are covered with pine trees, that march forward and climb to the summit of Mount Wilson. A trail, two feet in width and $9\frac{1}{4}$ miles long, connected the top of the lonely mountain with the plain beneath, when the astronomers began to build their observatory.

Fighting the battle of scientific observation against fierce onslaughts of weather

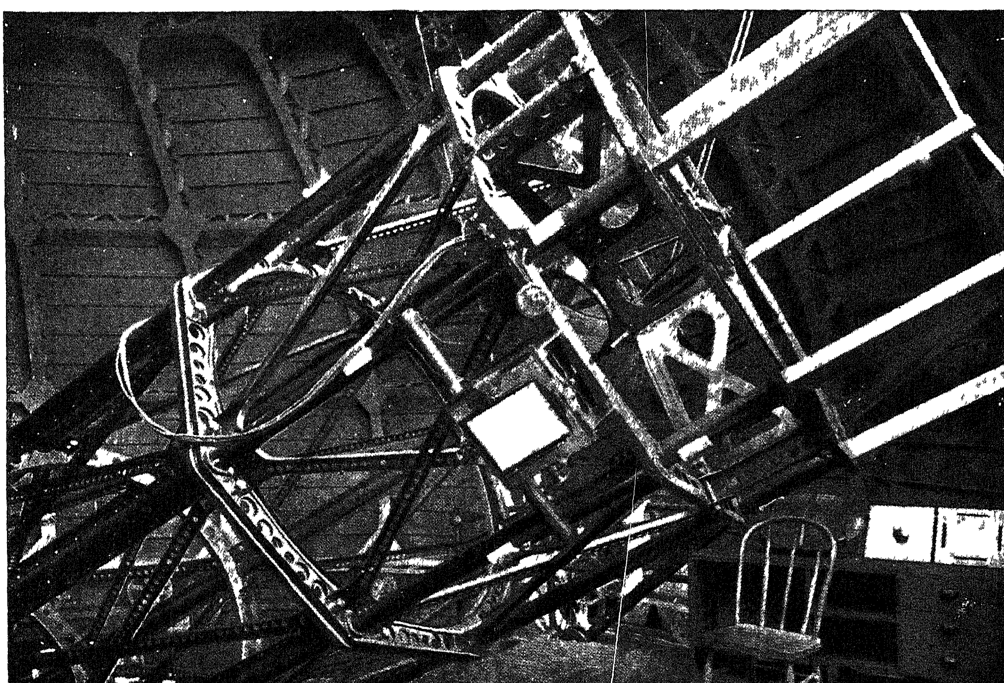
Hundreds of tons of building material had to be carried up this steep and narrow trail. Bit by bit it was packed on donkeys and mules, and sent up the mountain. It was very slow work, and very troublesome, and the trail was at last widened to admit of motor trucks being employed. The torrential rains of the rainy season brought down on the newly made road thousands of tons of earth and rock.

However, the road was remade, and by the middle of 1907 a good part of the observatory had been built. At the present time, the observatory is equipped with a great deal of apparatus which has enabled the men of science there to undertake new and extremely valuable researches. Great difficulties have been met with in connection with the newest and most powerful telescope, but these difficulties have been overcome with all of the instruments which are now in use. Every year sees the application of new methods of work, which result in greatly extending our knowledge of the sun and stars.

HOW THE SUN IS PHOTOGRAPHED



THE 60-INCH MIRROR-TELESCOPE IN THE DOME OF MOUNT WILSON OBSERVATORY

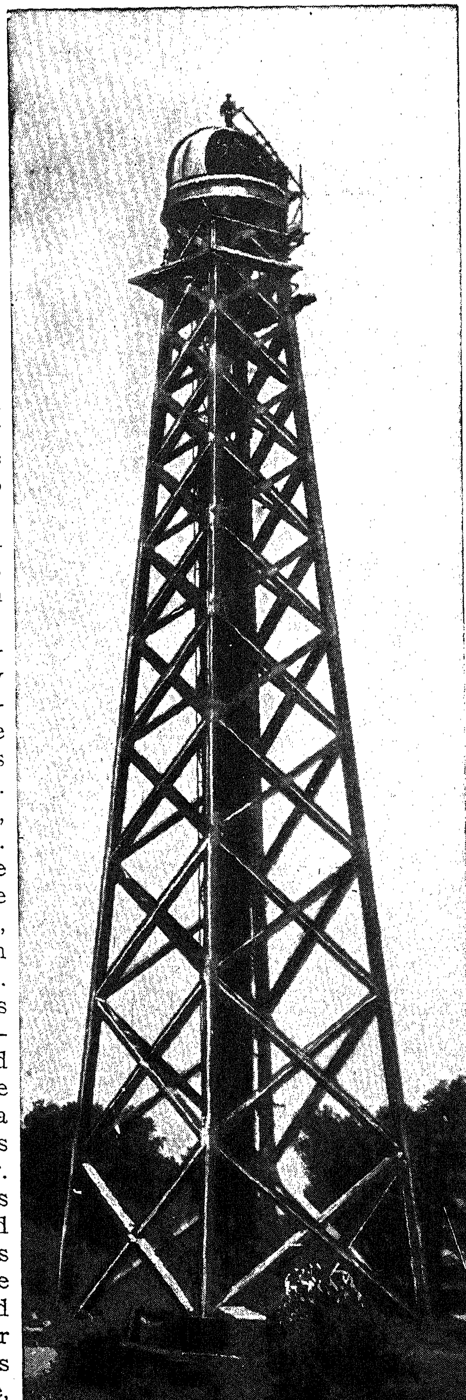


THE PHOTOGRAPHIC CAMERA IN THE FOCUS OF THE REFLECTING MIRROR

The upper picture shows the great sun telescope, and the machinery that moves it. The steel frame work in the middle of the telescope supports mirrors which receive reflections from the big 60-inch mirror in the base of the telescope. These mirrors reflect light out of the frame into spectroscopes, or a photographic camera, as shown in position in the lower picture.

The climatic conditions at Mount Wilson have been found to be excellent. From April to August, fog rolls in from the ocean, and at night covers the valley. But the fog-cloud seldom rises higher than three thousand feet. Far below the observatory it stretches — a strange, dim, tumbled sea, breaking against the dark heights, and shutting out every glimpse of earth. The moonlight turns it into a floor of pearl and silver; as it lifts and scatters at daybreak, the sun colors it with lilac, rose and gold.

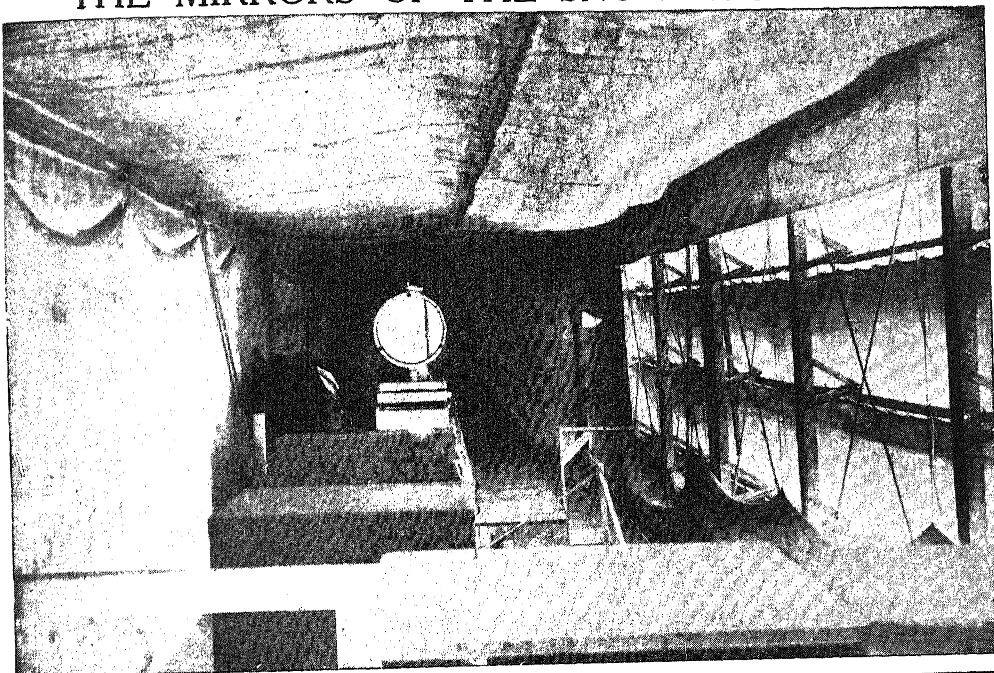
By night, the gorgeous over-arching sky is of a wonderful transparency; the stars have an unearthly brightness and a marvelous beauty. Very near they seem, even to the naked eye. By day the heavens are of a very deep blue color, and in the thin, pure air the sun puts on a dazzling brightness. During many months of the year the sunshine is continuous; and though in summer the sea-breeze blows for a part of the day, it is of very low velocity. Many of the buildings of the observatory, and particularly the towers in which instruments are fixed, are constructed of a skeleton of steel or iron. The wind blows through the structure, instead of beating against a solid wall of brick or stone. In this way vibration is much lessened; in fact, in ordinary weather it is not felt at all.

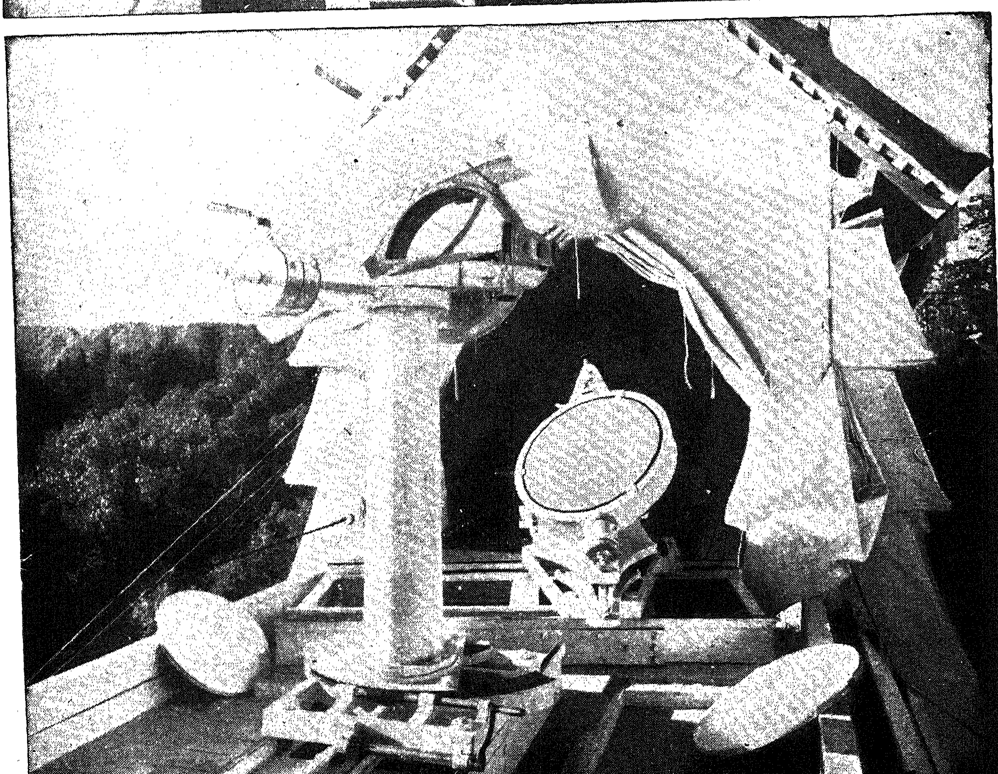


160-FOOT TOWER TELESCOPE AT THE MOUNT WILSON OBSERVATORY

The most remarkable of the towers is that which was built in 1910. It stands a hundred and sixty feet above the ground, and beneath it is a large well seventy-eight feet deep. Each of the steel members of the tower is guarded from the wind by being enclosed within an outer tube of steel, and separate foundations of concrete are made for the inner and outer portions. There are thus two towers, one within the other. On the inner tower are fixed the two mirrors and the object-glass of the telescope. The beam of light from the mirrors is sent straight down into the room at the base of the tower where the solar image is formed. To protect the beam from disturbing air-currents, it is enclosed in an iron tube, five feet and a half in diameter; the tube is lined with sheet-iron and covered by a canvas shield. In the well is a powerful spectroscope, which analyzes the light from any part of the large image of the sun. This image must not change its position during the exposure of a photograph. That is why extraordinary precautions are taken to build a telescope that shall not vibrate.

THE MIRRORS OF THE SNOW TELESCOPE

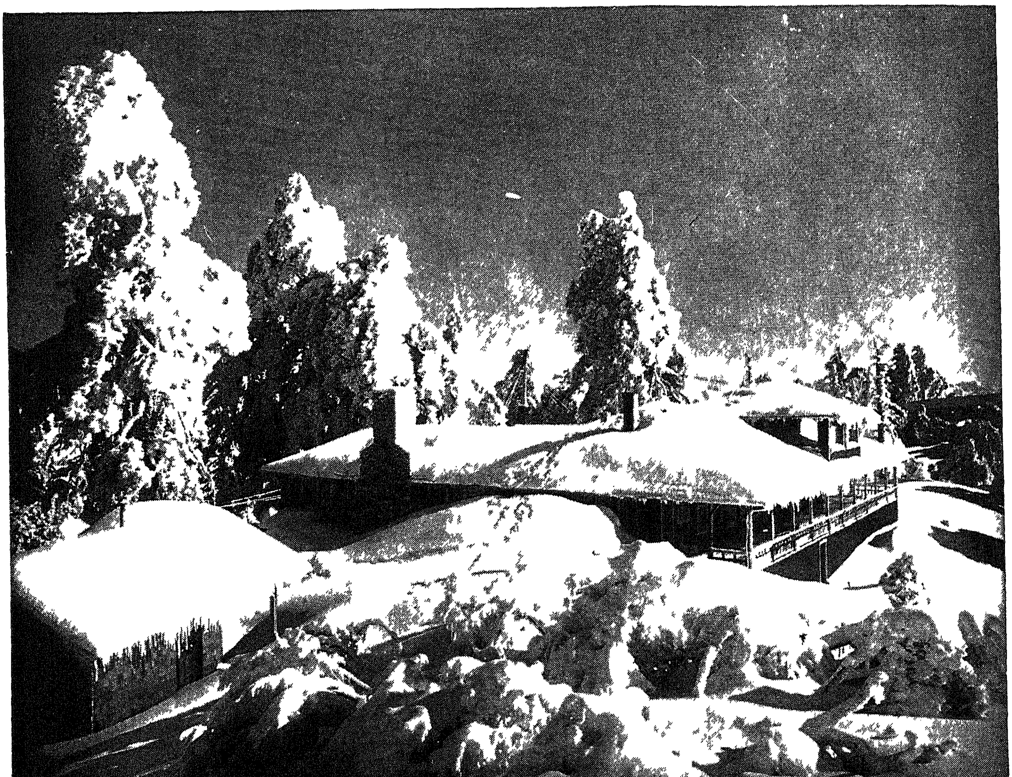




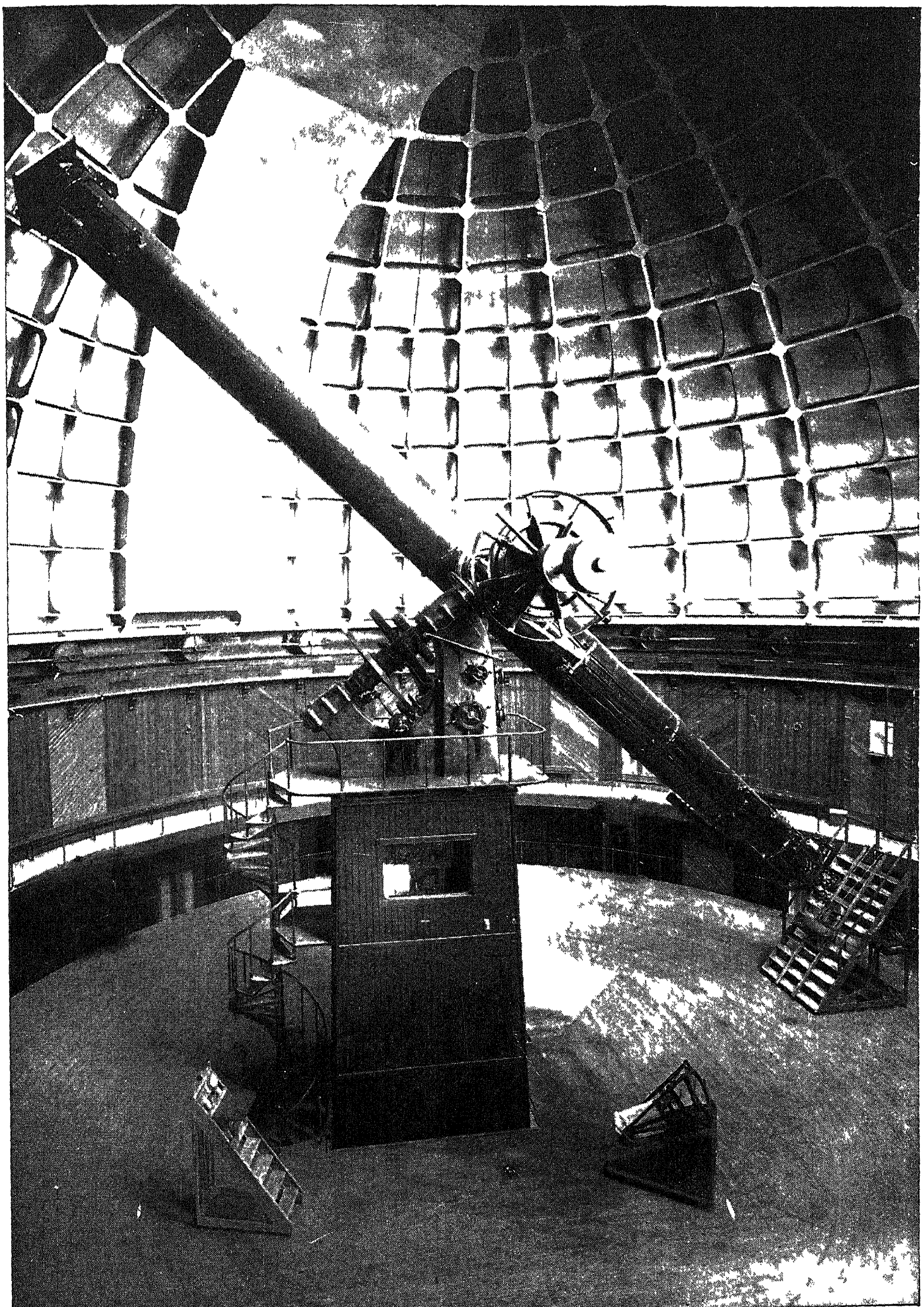
Light from the sun strikes the Snow cœlostat, the lower mirror shown in the bottom picture, and is reflected to the plane mirror above it. This mirror reflects the light on to a concave mirror 145 feet away, at the end of the canvas-covered interior shown in the upper picture.

Yet an absolutely fixed telescope has a difficulty to overcome It cannot be shifted so as to follow the movement of a heavenly body So the instrument called a "cœlostat" is used on Mount Wilson It consists in principle of a set of revolving mirrors, and its position can be altered so as to reflect any portion of the sky on to the lens of the fixed telescope The mirrors stand in the opening of the dome, and they can be moved about on rails and adjusted to any position They are twelve inches thick, and they are encased in closely fitting water-jackets, through which a stream of water is kept circulating This is done to prevent the mirrors from getting hot For heat makes the glass swell and disturbs the reflecting surfaces, with the result that the beam of light thrown into the telescope is so distorted that a useless image is sent down into the well

There are two kinds of telescopes, the refracting and the reflecting telescope An ordinary opera-glass or field-glass is a refracting telescope, so is any telescope in which a lens is used as an object-glass The lens, which in its simplest form consists of a round piece of glass with a convex or bulging surface, bends or refracts the rays of light that pass through it The largest practical telescope in which lenses are fitted is the Yerkes telescope, at Lake Geneva, Wisconsin The Yerkes lens is forty inches in diameter, the front-glass is made of crown glass, the inner glass is made of flint glass, and they weigh together about five hundred pounds The lens is of extraordinary purity and transparency, but, as it is three inches thick, it absorbs a considerable amount of light The lens unfortunately acts as a prism, and bends the different light-waves in different directions, thus producing several colored images of one object instead of a single white image But this is largely corrected by the use of crown and flint lenses in combination



THE WINTER BEAUTY THAT SURROUNDS MOUNT WILSON OBSERVATORY



THE 36 INCH REFRACTOR, LICK OBSERVATORY, MOUNT HAMILTON, CALIFORNIA

This is the second largest refracting telescope in the world, the objective having a clear aperture of 36 inches It has a focal length of 57 ft 10 in The point of suspension of the telescope tube is 36 feet from the floor. The dome, 76 ft. in diameter, like the observation platform, is moved by water power

How Newton overcame the difficulty common to all refracting telescopes

This difficulty is the fault of all refracting telescopes; and Sir Isaac Newton, who was the first man to discover the cause of the fault, managed to get rid of it by inventing the reflecting telescope. He placed a mirror, which was formed of metal and hollow or concave in shape, at the bottom of a tube. The light fell on the highly polished surface, and from there it was reflected to a little flat mirror near the top of the tube. In the side of the tube opposite to the little mirror was a hole; in this hole the eyepiece was fixed. The beam of light fell on the large mirror; the large mirror reflected it on to the little mirror; and the little mirror transmitted it to the eyepiece. In this way the waves of light were kept from being broken up by passing through a glass lens.

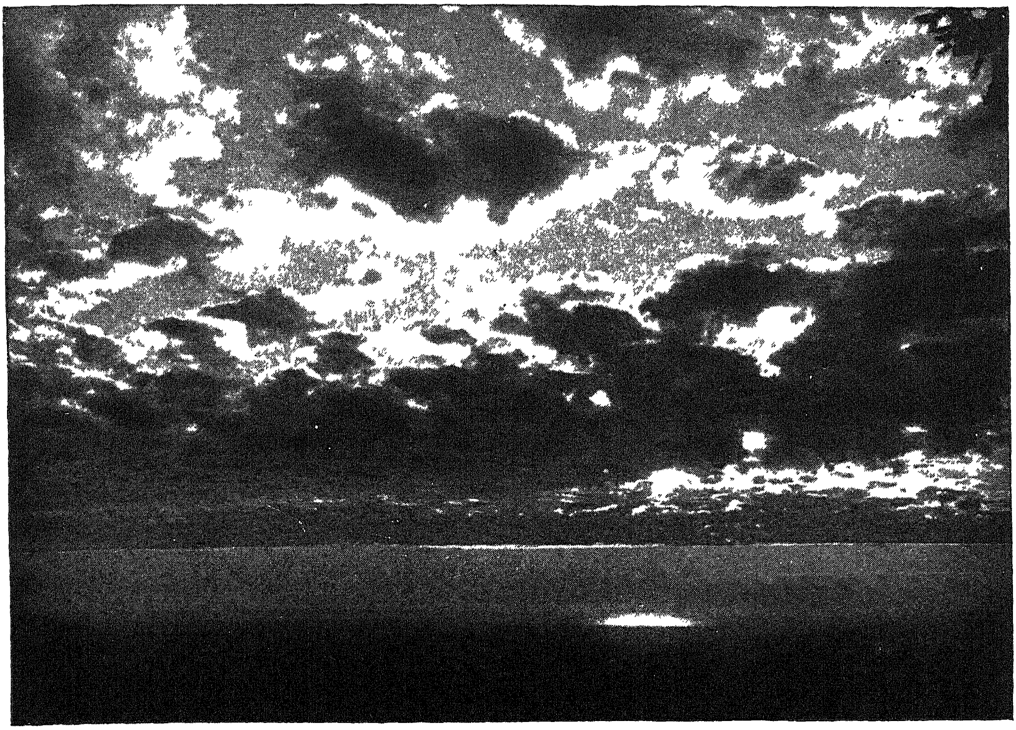
Unfortunately, the little mirror which was placed in the middle of the tube cut off some of the light; and, moreover, the polished metal surfaces could not be made to reflect as much light as a piece of transparent glass will let through. So what was gained in not breaking up the light-waves was partly lost through the arrangement of the mirrors, and through the defects of the reflecting surfaces. Metal mirror-telescopes, however, can be made much more cheaply than refracting telescopes, and much fine work has been done with them.

The Earl of Rosse, for instance, constructed, in 1845, at Parsonstown, in Ireland, a mirror-telescope that had a diameter of 72 inches. It was for many years the largest in the world. The Rosse telescope consisted of an enormous tube, at the bottom of which was a huge mirror of metal. At the time it was constructed, engineering methods were inadequate to provide a proper mounting for so gigantic an instrument. It was swung in chains, and flanked by two stone walls that greatly restricted its range, yet some remarkable discoveries were made by means of it. The observer stood upon a platform far above the ground, and, looking down into the tube, saw there the image of the object. It was impossible to maintain the telescope steadily fixed for hours at a moving star; and it was impossible also to make accurate measurements with it.

The great 60-inch and 100-inch reflecting telescopes at Mount Wilson

The 60-inch reflecting telescope was fixed on Mount Wilson in 1907, the year of the great snowstorm. The huge tube is hung between the arms of a massive cast-iron fork, and pointed through an opening in the dome of the observatory. The dome is moved by electric motors, so that the opening in it also follows the course of the object which the clock-driven mirror telescope is photographing. Between the dome and the floor hangs a platform, and here the astronomer stands, looking into a second mirror, which receives the image formed by the great five-foot mirror at the end of the tube. Opposite the second mirror is a double slide plate carrier, fixed to the skeleton framework of the tube. The image is projected upon the plate and photographed. The five-foot mirror weighs one ton, and was cast by the French Plate Glass Works at St. Gobain, France — the only firm at that time with the plant for making discs of such magnitude. After being carefully tested in the workshop of the observatory, it was ground and figured by Professor G. W. Ritchey to a true paraboloidal form. The glass of these large mirrors has to be perfectly annealed, and no strain must be found in it. That is why there was so much difficulty over the $4\frac{1}{2}$-ton mirror, with a diameter of $8\frac{1}{3}$ feet, for the 100-inch telescope, similar in design, but on a much larger scale, for which Mount Wilson waited so long. Again and again the disc was cast and annealed, and again and again it broke. The disc finally adopted, however, has proved very satisfactory.

This, the greatest of all telescopes up to the time of the completion and erection of the 200-inch reflector, was named for the late Mr. John D. Hooker, who provided the funds for the optical parts. The rest of the expense was borne by the Carnegie Institution of Washington.



THE GLORY OF THE SUN SETTING ON THE FAR HORIZON

A STORM IN THE MOUNTAINS, AS SEEN FROM THE MOUNT WILSON OBSERVATORY

The camera is used in conjunction with the telescope in modern astronomy

Many difficulties of construction had to be overcome. The long delay in securing a suitable disc for the large mirror was in some ways an advantage, for it gave opportunity for extensive studies of the best type of mountings and protection, and for investigations in many other lines.

Nearly everything is done by photography in a modern observatory. The photographic plate is steadier than the human eye, and it never grows tired. Moreover, it can record waves of light which are invisible to us, and trace the path of myriads of stars which we cannot see even through the most powerful telescope.

One of the most remarkable of all photographic instruments is that invented by Dr. George Ellery Hale, the director of the Mount Wilson Observatory. It is called a "spectroheliograph", and is used for taking photographs of the sun by the light of a single element flaming on the solar surface.

The wonderful instrument which picks out a single one of the sun's rays

As is well known, light can be broken up into a band of rainbow colors by passing it through a three-sided piece of glass. This band of colors is called a "spectrum". The curious thing about it is that it is full of dark lines as well as tints of color.

The dark or absorption lines in the spectrum of sunlight, and of other stars, indicate the presence of cooler gases in the atmospheres of these bodies. If the sun had no atmosphere, its spectrum would show only bright lines. One line in the spectrum representing helium, which is one of the elements into which radium decomposes, was found in the sunlight spectrum, and also in some stars, many years before the actual substance was discovered on earth. The spectroheliograph devised by Dr. Hale takes a photograph of the sun with a single light-ray proceeding from only one of the many elements which are shining in the sun and flooding the earth with sunshine. In this way it is possible to obtain a large and exact photograph of, for instance, all the calcium which is blazing on the surface of the sun. Or the calcium-ray can be shut out, and only the ray produced by the iron clouds in the sun can be photographed.

This is how it is done. The large solar image from the 60-inch telescope or one of the tower telescopes is made to move across a narrow slit. Behind the slit is a prism of glass, which breaks the light up into a long band of spectrum colors. The spectrum is thrown on to the lens of a camera tube. Behind the lens is another slit, and behind the slit is a photographic plate mounted on a carriage which runs on rails, and is timed to move exactly at the same rate as that at which the solar image from the telescope moves across the first slit.

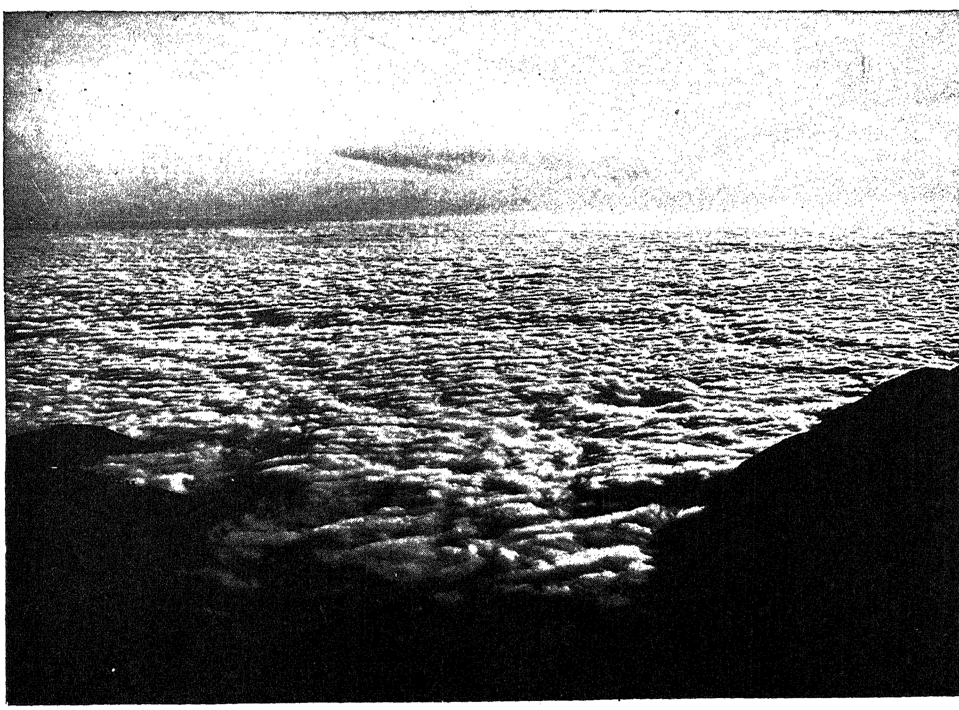
How a photograph of the sun may be taken to show only one of its elements

The delicacy of the operation is mainly a matter of adjusting mirrors and lenses so that only a certain line in the twenty thousand lines of the spectrum enters through the photographic slit. This adjustment is, of course, made before the solar image and the photographic plate are set in motion.

Suppose, for example, that an astronomer wishes to take a photograph of the sun by the light of the calcium it contains. In the extreme violet region of the spectrum there are two broad, dark bands known as *H* and *K*. These represent calcium, the metallic base of lime.

The telescope is directed at the sun, and the image formed is thrown on a prism, and there broken into a band of color, which is reflected on the lens of the camera, and from there thrown on the screen in the middle of which is a slit. Then either the telescope or the prism of glass is moved until one of the two lines *H* and *K* falls exactly through the slit on to the photographic plate—all the rest of the lines and colors being blocked out by the screen. When this has been done the double movement of the solar image and the photographic plate is started.

THE SUNNY SIDE OF FOG — A BANK OF MIST VIEWED FROM MOUNT WILSON



THE DENSE CLOUDS OF FOG ABOVE WHICH MOUNT WILSON TOWERS IN SUNLIGHT

The result is that every wave of light created by the glowing calcium clouds in the sun strikes against the photographic plate as the solar image is slowly moved across the slit of the prism.

To put it roughly and briefly, the sunlight is broken up and then filtered, and only that fragment which represents some special element is allowed to pass through the filter and record itself upon the plate. Thus is obtained a picture of the sun lighted by the rays from a single element glowing there.

By means of the spectroheliograph, astronomers are now able to analyze the sun more easily and exactly than a chemist could analyze a furnace a few years ago. For this wonderful instrument has now been improved so that it gives an accurate photograph of vapors of a single element lying at a low level on the sun, light-waves from the same vapors at a high level being blocked out with the rest of the spectrum. Or those at high levels can be photographed alone. Thus the true structures of the solar phenomena are now being discerned; and some of the most fundamental problems of the universe are in a way to be solved at the Mount Wilson Observatory.

Differences of temperature on the surface of the sun can now be distinguished by means of the spectroheliograph; and this new knowledge has proved of great value in examining the vapors associated with sun-spots. Spectroheliographs are now used daily in England, France, India, Sicily, Spain and the United States. The observatories in which they are employed are connected together in an Astronomical Union, which is making a combined attack on the sun from different parts of the world. In time, very important additions to our knowledge of solar phenomena will be obtained; and perhaps we shall then be able to forecast to some extent the play of some of the forces in the sun which vitally affect the life of everything on our earth.

Much continuous daily research in all the solar observatories is still required. For instance, there are twenty thousand lines in the spectrum of sunlight, and hundreds of these lines need to be examined over and over again with the spectroheliograph before we obtain separate photographs of the substances of the sun.

The inconceivable forces set in play on the surface of the sun

We already know a great deal about the calcium, hydrogen and iron glowing in vapor at various levels above the solar shell. It is possible that the enormous heat of the sun may produce substances which we cannot imitate in our laboratories, but in various ways we are gradually coming to understand the theory of what takes place in the gigantic furnace of the sun. Possibly we shall never be able to reproduce in any experiment all the conditions of solar heat.

The forces set in play merely on the outer portions of the sun's globe are simply inconceivable. Perhaps the explosions that take place when a battery of guns on a battleship fires a salvo are as striking an example of the force of ignited gases as we are familiar with. Now, suppose that every foot of space in the State of New York were covered with such guns, all pointed upward, and all being discharged at once. The result would compare with what is going on in the sun as a boy's popgun compares with the big guns of the battleship.

Has a spot on the sun anything to do with the price of wheat?

One of the problems in regard to the sun which the astronomers are tackling is that relating to variations of heat. We can take it for granted that the sun will continue to radiate heat for many centuries to come at practically the present average rate. But do we know that the rate is absolutely constant? May not fluctuations occur of sufficient magnitude to affect our climate, and to be reflected in change in the quantity of crops and the price of wheat?

Until a short time ago this question had been tested in only the roughest way. It was known that sun-spots passed through a regular cycle of change, occupying about eleven years. A curve was accordingly

drawn, showing the varying number of sun-spots, and this curve was compared with the curve representing the varying price of wheat. As the two were thought to show some correspondence in form, it was held that the price of wheat was determined by the solar activity as measured by the number of spots.

The whole question, however, is still in its early stages, and little has been learned yet which is absolutely definite and trustworthy. Work of special importance is being carried on by Dr. Abbot of the Smithsonian Astrophysical Observatory with very ingenious apparatus. At regular intervals the image of the sun is split up into the band of colors of the spectrum, and this band of colors is made to move slowly over an instrument which can record the heat of a candle at the distance of a mile or more. In other words, the instrument measures a rise in temperature of less than one millionth of a degree. It is called a "bolometer," and we have already described it.

The measurements were begun several years ago, and important changes in the solar radiation have been detected. Some time may elapse, however, before we can be sure that we are in a way to discover that law of the variations of the heat of the sun which will enable mankind to become more the master of its immediate fate than it is now.

The extraordinary changes that may take place in the inside of the sun

From the results obtained it seems likely that the solar heat temporarily undergoes actual change which is not to be ascribed to any modification of our own atmosphere.

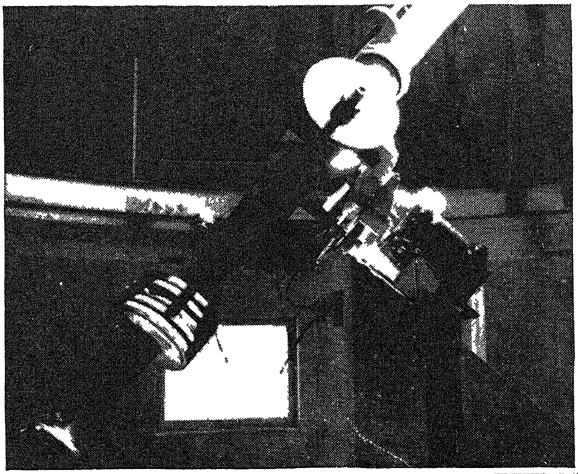
Photographs taken of the sun's surface by means of the spectroheliograph seem to show that these changes of heat are brought about by violent currents which convey large quantities of heat from the depths of the sun to the exterior. But the problem is not simple. For the increased radiation produced by great solar activity may quickly be checked by the diffusion, through the atmosphere of the sun, of the materials thrown upward by the violent eruptions. Simultaneous observations at several widely separated mountain ranges are greatly to be desired. By this means it would be possible to ascertain if local changes in the earth's atmosphere are in any way concerned in the apparent solar changes.

Continuous study without weather interruption of variations of solar heat

Moreover, the work should go on without the interruptions caused by the rainy season. For example, when the rains begin to fall at Mount Wilson, there is a dry season at the solar observatory at Kodaikanal, in South India, which has an elevation of 7000 feet. So astronomers of the two observatories could coöperate in studying the variations of solar heat, special regard being given to a standardization of the bolometers and other instruments of measurement. An Australian station would also help greatly in accomplishing very important results, and it is hoped that provision may soon be made to establish such a station.

It might be thought that if there are real fluctuations in the sun's heat, which cause marked changes in the temperature of the earth, the effect would be obvious and easily detected. But as a matter of fact the atmosphere and the weather of our earth form a very complicated mass of phenomena, in which the sun's varying heat is only one factor. The rotation of the earth, and the complicated movements of its atmosphere produce effects of a very complex kind. These effects have to be traced and disentangled before we can clearly discern the part played by fluctuations in the solar heat on our weather. Studies of the solar radiation have been undertaken by the Astronomical Union, and coöperation in the science of weather has been started by some of the weather bureaus. Thus there are many investigators now engaged in an exhaustive study of one of the most practical and important points in astronomy. The work, however, is barely begun. It must be continued for many years before it can have a direct effect upon the lives of the whole of the human race.

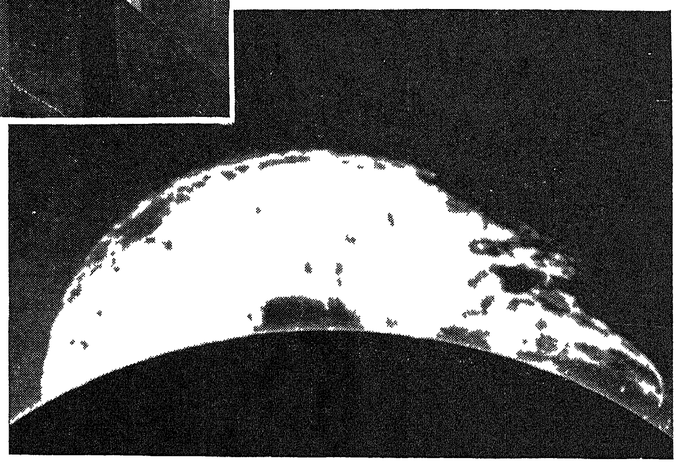
PHOTOGRAPHING THE SUN'S GASEOUS ENVELOPE



The coronagraph (left) is a photographic telescope, with which it is possible to observe the sun's corona The coronagraph was invented in 1930 by a French astronomer, Bernard Lyot Formerly the corona was visible only during a total eclipse of the sun With the coronascope we can follow daily changes in the appearance of the corona.

All photos Harvard University Observatory

Incandescent red solar prominences of hydrogen gas photographed by the coronagraph These clouds of gas are generally found in the sunspot zones



High-altitude observatory at Climax, Colorado The observatory, which houses the coronagraph, is at an altitude of two miles Hence its sensitive instruments are not so apt to be affected by dust and gases, which are particularly heavy in lower levels of the atmosphere.